CHAPTER 4
PRELIMINARY DESIGN (PHASE 1)

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4.1 Alignment Plan

4.1.1 Design Criteria

(1) Outline of Proposed Design Specifications

Table 4-1 Key Features for Alignment Planning

	Items	Proposed Design Specifications
1	Design speed	Tunnel section: 100 km/hr Viaduct & At-grade section: 120 km/hr
2	Minimum horizontal curve radius	Main line: 250 m Main line turnout curve: 160 m Workshop/Depot (W/D) line: 160 m W/D line turnout curve: 120 m Platform section: 1,000 m
3	Minimum vertical curve radius	Over 600 m horizontal radius 3,000 m Less than 600 m horizontal radius 4,000 m
4	Maximum gradient	Main line: 4% Platform section: 0.2% Stabling line: 0.2% Turnout section: 0%
5	Platform length	Total: 170 m

Source: JICA Study Team

(2) Design Speed

Generally, operation at a speed in excess of 100 km/hr is not allowed in the tunnel section of the central city area because the distance between stations is mostly within 1 km. Also, JICA Study Team is recommending the overhead conductor rail as the power supply system. The maximum operation speed of this system is limited to less than 80 km/hr. However, railway technology is progressing day by day and it will be able to deliver higher speeds in the future. Furthermore, Metro Line 4 has a possibility to be extended to the suburbs, with perhaps an ultimate service length of over 40 km. Thus it should be considered as a rapid service in the future. To allow for the possibility of higher speeds in the future, the alignment planning at this stage takes into consideration the need for gentle curve radii, gentle gradients, long transition curves, etc., all subject to the need to improve operational efficiency. In case of viaduct and/or at-grade track sections in the suburbs, a maximum speed of over 100 km/hr will be very useful for reducing travel time. The selection of a design speed of 120 km/hr or of 100 km/hr makes little difference to the construction cost so that it is better to specify the higher speed from the beginning.

(3) Cant and Curve Speed Limit

1) The curve speed and cant are calculated according to the following formula:

Equilibrium cant (a) $C = 11.3 \cdot \frac{V^2}{R}$

Maximum permissible speed (b) $V_m = 4.3 \cdot \sqrt{R}$

(c) $V_m = 0.298 \cdot \sqrt{R \cdot (C_m + C_d)}$

Where

R	: curve radius (m)
V_m	: maximum permissible speed (km/hr)
V	: applied speed (km/hr)
C	: equilibrium cant (mm)
C_m	: actual cant (mm)
C_d	: maximum permissible deficiency of cant (mm)

Formula (a) is derived from the theory of cant which consists of train speed, the acceleration of gravity and centrifugal force.

Formula (b) is derived from the equilibrium of forces which consists of curve radius, train speed, gauge, centre of gravity of the car and safety factor. It is applied with a safety factor of 3 and the centre of gravity height is assumed to be 1,650 mm from the rail level.

Formula (c) is derived from calculating back from the speed of the equilibrium cant formula, i.e., “C = Cm + Cd”. In this case, Cd is the applied maximum deficiency of cant.

2) The maximum cant is proposed at less than 200 mm. It is calculated from the static stability of the train which consists of the balance among the gauge, the cant, the height of the centre of gravity and gravity. It results to 200 mm in case of a safety factor of 3. However, a maximum cant of less than 150 mm is preferable if passenger comfort is taken into account.

3) The deficiency of cant is proposed at less than 100 mm. However, a cant deficiency of less than 60 mm will provide a better riding quality.

4) The actual cant is proposed at approximately 70% of equilibrium cant which satisfies the conditions regarding speed limit, maximum cant, deficiency of cant and the ride quality index.

5) Speed limits in the curve sections are calculated in accordance with formulas (b) and (c) above. The results of these calculations considering the above conditions are shown in Table 4-2.

Table 4-2 Proposed Actual Cant and Speed Limit

Curve Radius (m)	Speed Limit (km/hr)	Actual Cant (mm)
250	65	135
300	70	135
350	75	135
400	80	135
450	85	135
500	90	135
550	95	135
600	100	135
700	100	115
800	100	100
1,000	100	80
1,200	100	70
1,400	100	60
2,000	100	40

Source: JICA Study Team

It should be noted that the abovementioned speed limit is not the operation speed. Operational speed restrictions may be introduced for sections as dictated by maintenance and operational requirements.

Proposed speed limit is rounded down to the nearest 5 km/hr.

Proposed actual cant is rounded down to the nearest 5 mm.

(4) Transition Curves

1) In general, transition curves should be installed at the contact point between a circular curve and a straight line, or at the points of transition of compound curves and reverse curves.

2) Transition curve is proposed in the form of cubic parabola curve for which the formula is:

$$y = \frac{x^3}{6 \cdot R \cdot X}$$

where X : length of tangential line ≑ transition curve length

R : radius of circular curve

Y : offset from tangent

X : Distance from the beginning point of transition curve on the tangential line

3) Transition curve length is calculated according to the following formula:

(a) $TCL1 = 0.6 \cdot C$

(b) $TCL2 = 0.01 \cdot V \cdot C \cdot k$

(c) $TCL3 = 0.006 \cdot V \cdot C_d$

Where V : curve limited speed (km/hr)

C : actual cant considering a possibility of speed up (mm)

C_d : actual deficiency of cant (mm)

k : corrected value (= 0.75 in standard gauge)

Formula (a) is decided by the “safety limit of avoiding a derailment caused by three-point-support”. Desirably, this limit is set at 400 times cant at least.

Formula (b) is decided by the “changing ratio of cant per second”. From the data based on our experience, the changing ratio limit of cant of 29 mm is applied for riding comfort in case of narrow gauge (1,067 mm). Therefore, it is recommended to apply the correction value k = 0.75 (≈1,067 mm/1,435 mm) in case of standard gauge.

Formula (c) is decided by the “increasing ratio of centrifugal acceleration”. UIC applies the increasing ratio limit of centrifugal acceleration of 0.03g.

The results considering the above are shown in Table 4-3.

Table 4-3 Proposed Transition Curve Length

R (m)	TCL (m)	TCL1 (m)	TCL2 (m)	TCL3 (m)
	To be proposed	0.6*C	0.0075*V*C	0.006*V*Cd
250	94	93	76	24
300	90	90	79	21
350	88	87	82	23
400	88	87	87	24
450	92	87	92	26
500	98	87	98	27
550	104	87	103	29
600	102	81	101	33
700	86	69	86	30
800	76	60	75	27
1000	60	48	60	21
1200	54	42	53	15
1400	46	36	45	15
1600	38	30	38	15
2000	30	24	30	12
3000	24	18	23	6
4000	16	12	15	6
5000	16	12	15	3
6000	12	9	11	3

Source: JICA Study Team

The proposed length is calculated in consideration of the possibility of a 5 km/hr speed up through each curve in the future.

(5) Vertical Curves

1) Vertical curves coinciding with horizontal transitions should be avoided. If such coincidence is unavoidable, the largest radius in practicable vertical curves should be planned.

2) In case of a change of gradient of less than 10 ‰, it is possible to omit the vertical curve.

3) Vertical curves coinciding with turnouts should be avoided.

4) Vertical curves are proposed as follows:

a)	Minimum desirable radius (Minimum acceptable radius if unavoidable)	3,000 m (2,000 m)
b)	Minimum radius coinciding with horizontal curve of less than 600 m radius (Minimum acceptable radius if unavoidable)	4,000 m (3,000 m)

(6) Gradients

1) The limits of gradient are proposed as follows:

a)	Mainline	:4%
b)	Workshop/depot access	:4%
c)	At stations (throughout the platform)	:0.2%
d)	On stabling lines	:0.2%
e)	At turnouts	:0%

Steep gradients impose a heavy load on bogies, brakes, tracks, etc. Thus, it is recommended to apply the maximum gradient at less than 3.5% while proposing 4% as the limiting gradient.

(7) Turnouts

1) Turnouts should not coincide with points where there are vertical curves and transitions.

2) The distance between continuous turnouts should be kept at more than 5 m.

3) The distance between the end of a transition curve and the end of a turnout should be kept at more than 20 m.

4) The speed limits in a turnout curve are calculated according to the following formula:

Speed limit $V = 3.0 \cdot \sqrt{R}$

where V : speed limit (km/hr)

R : turnout radius (m)

The above formula is derived from the equilibrium of forces which consists of curve radius, train speed, gauge, centre of gravity of the car and safety factor. It is applied with a safety factor of 6 and a centre of gravity height of 1,650 mm from the rail level.

The speed limits in turnout curves are proposed as shown in Table 4-4.

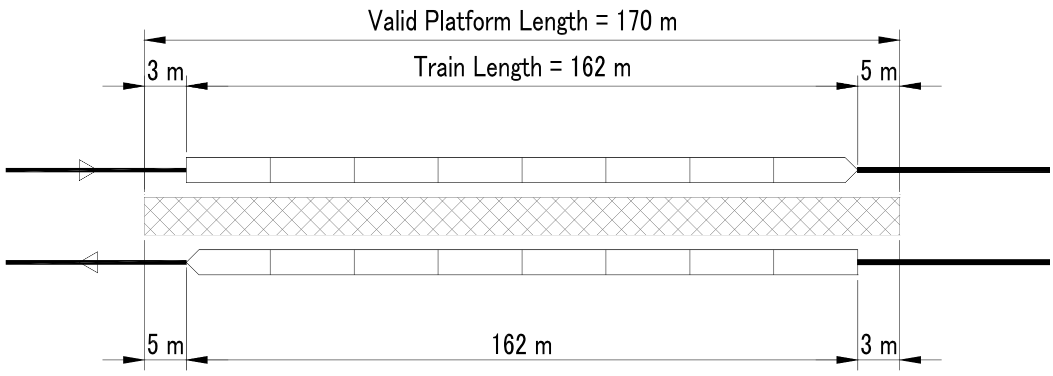
Table 4-4 Proposed Type of Turnout and Speed Limit in Turnout Curve

	Type of Turnout	Speed Limit (km/hr)
Main line	No.8 turnout	35
	No.10 turnout	45
Workshop/Depot	No.6 turnout	20
	No.8 turnout	30

Source: JICA Study Team

(8) Platform Length

The proposed platform length is shown in Figure 4-1 below:

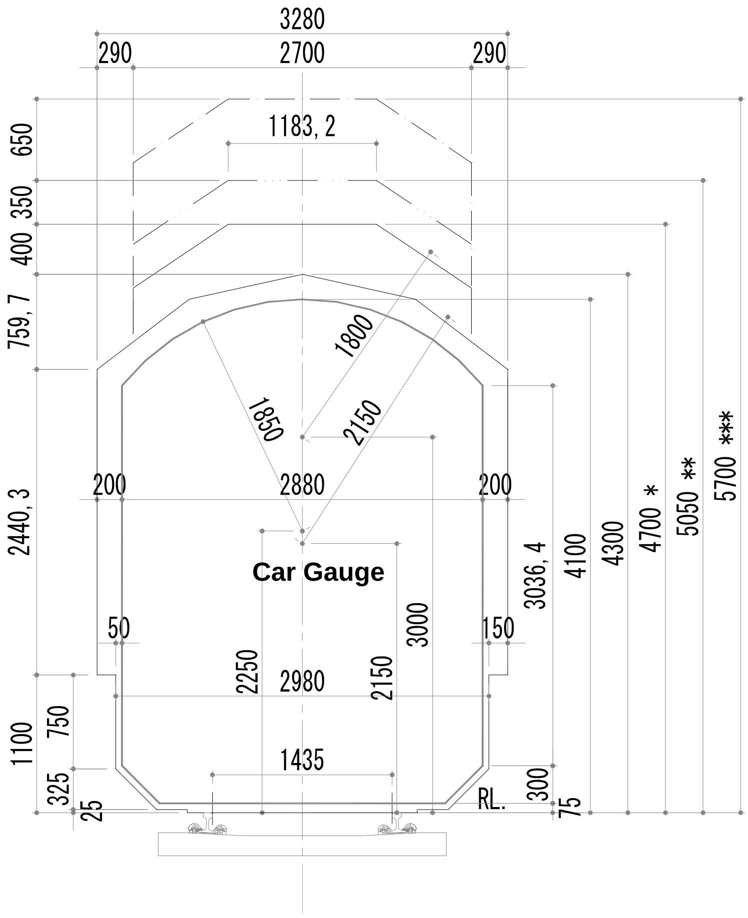


Source: JICA Study Team

Figure 4-1 Proposed Platform Length

(9) Proposed Structure Gauge and Car Gauge

The proposed structure gauge and car gauge are shown in Figure 4-2 below.



Source: JICA Study Team

Figure 4-2 Structure Gauge and Car Limit Gauge

Note:

* This height is the limit for the structures in tunnel section except for trolleys, catenaries and insulated supports.

** This height is the limit for an overbridge and/or the platform roofing, except for trolleys, catenaries and insulated supports.

*** This height is the limit for ordinary structures, except for trolleys, catenaries and insulated supports.

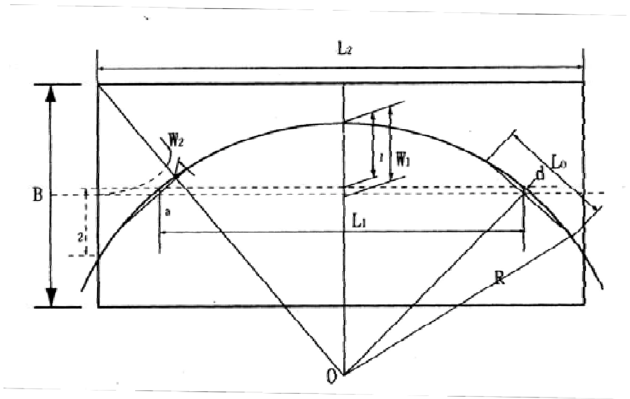
(10) Extension of the Structure Gauge in the Curve Section

The extension of the structure gauge is calculated according to the following formula:

$$W_1 = R - \sqrt{\{(R-d)^2 - (L_1/2)^2\}} \qquad \text{Strict formula}$$

$$d = R - \sqrt{\{R^2 - (L_0/2)^2\}}$$

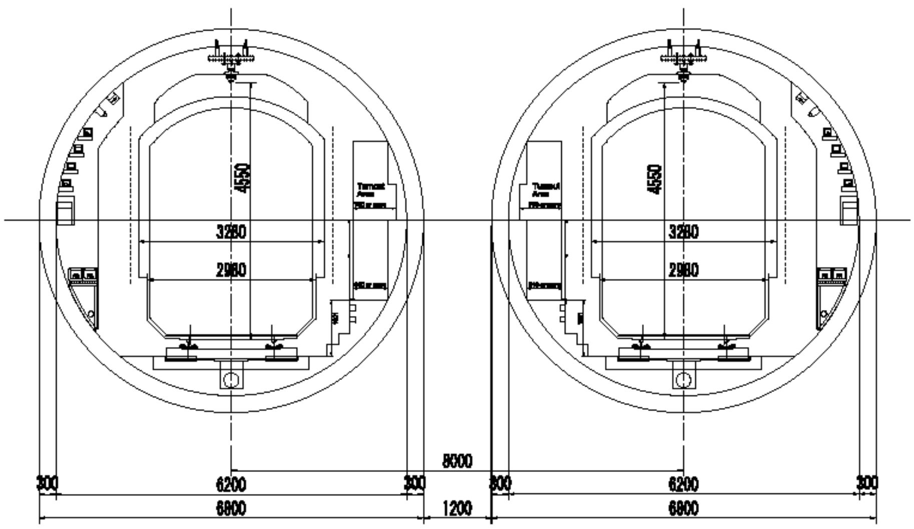
$$W_2 = \sqrt{\{(R + B/2 - W_1)^2 + (L_2/2)^2\}} - R - B/2 \qquad \text{Strict formula}$$



(11) Design Gauge

1) Tunnel Section

Shield tunnel external diameter:	6.8 m
Shield tunnel internal diameter:	6.2 m
Minimum distance between tunnels:	1.2 m

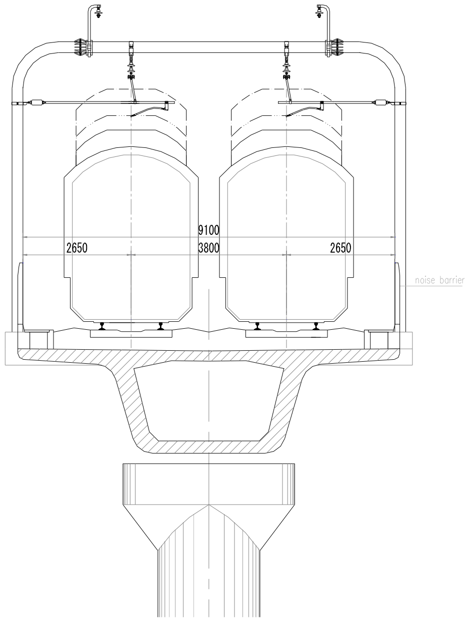


Source: JICA Study Team

Figure 4-3 Shield Tunnel Cross Section

2) Viaduct Section

Between tracks: 3.5 m

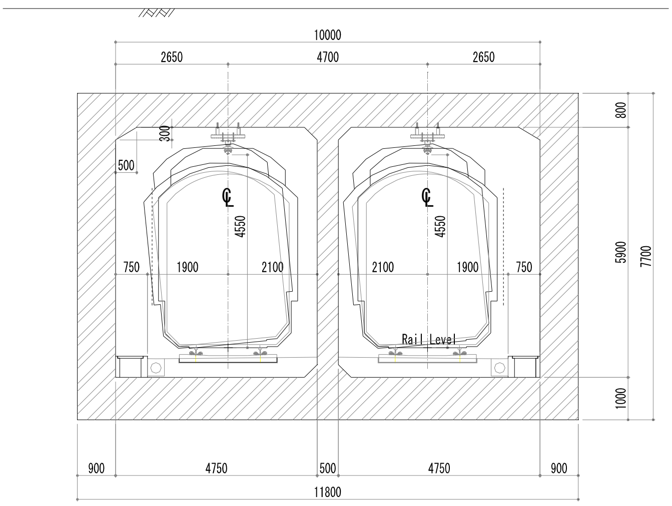


Source: JICA Study Team

Figure 4-4 Viaduct Cross Section

3) Culvert Section

Between tracks: 4.7 m

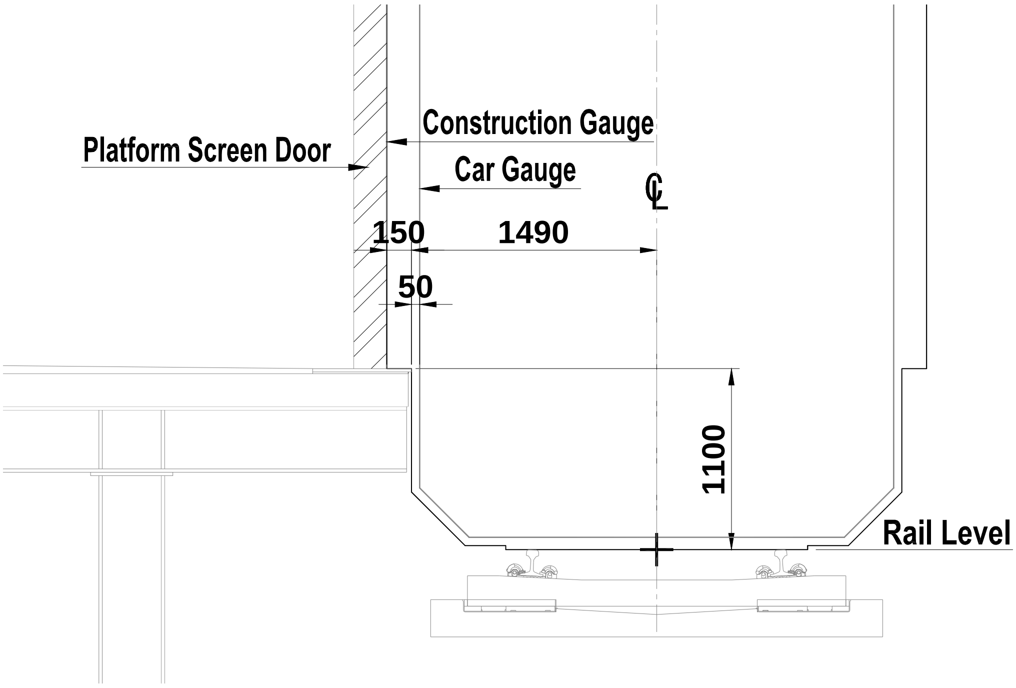


Source: JICA Study Team

Figure 4-5 Culvert Cross Section

4) Platform Section

The proposed distance between the platform structures and the car body is as shown below.



Source: JICA Study Team

Figure 4-6 Platform Section

4.1.2 Alignment Plan

(1) Alignment Planning Methodology

The alignment is planned on the basis of the approved route according to design criteria (refer to Section 4.1.1). It takes into consideration some control points (refer to Figure 4-8) and general conditions confirmed by the results of the topographical survey. Topographical maps with a scale of 1/2,000 (1/1,000 around stations) were used to display the results of the topographical survey.

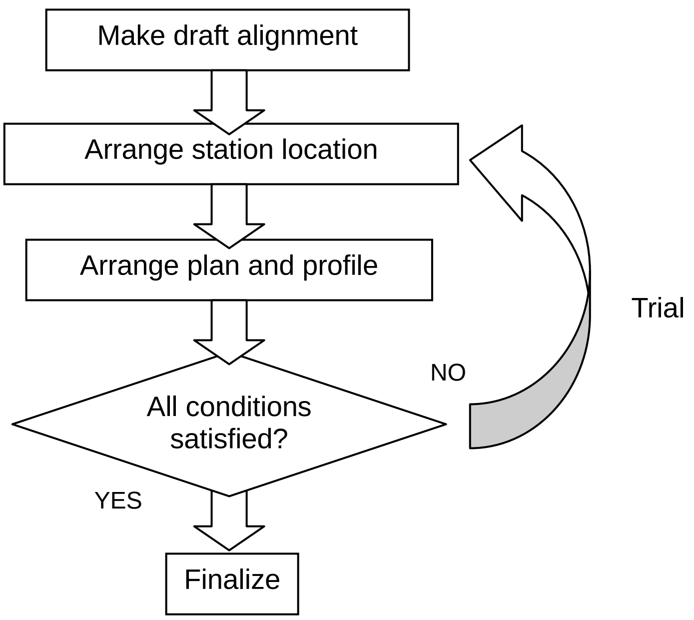
The basic features of the approved route are shown in Table 4-5.

Table 4-5 Basic Features of Metro Line 4 for Phase 1

Item	Basic Features
Outline of the Route	El Malek El Saleh – El Giza – Pyramids Rd. - El Remayah Square – Behind GEM - Hadayek Al Aharam – Beside Ring Road
Route Length	16.1 km
Number of Station	15
Underground Section	16.1 km/15 stations
Workshop/Depot	On ground

Source: JICA Study Team

The planning methodology is as shown in Figure 4-7:



Source: JICA Study Team

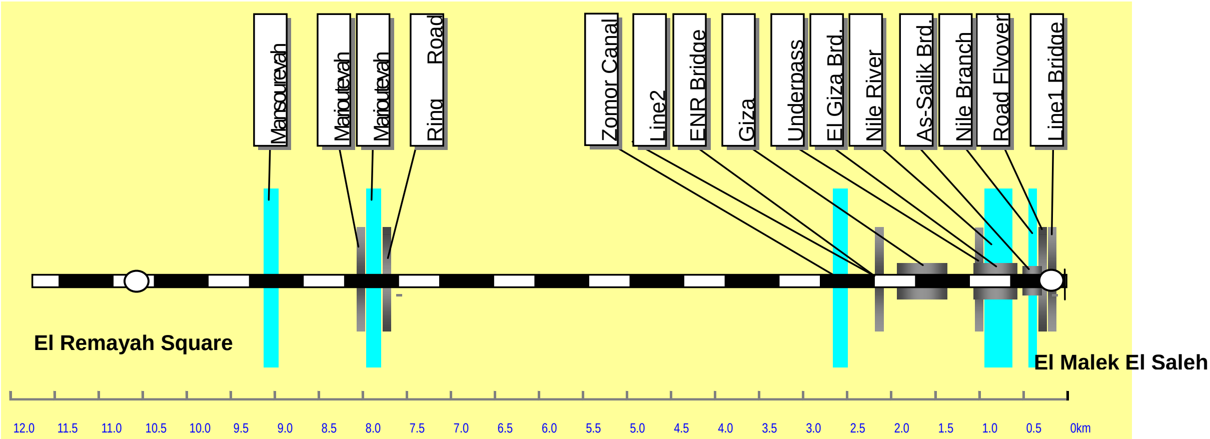
Figure 4-7 Planning Methodology

(2) Control Points and Basic Policy

There are some control points which restrict plan preparation and profile, in addition to the station locations and types. There are many conditions which should be considered, namely: existing structures, surface situation, road traffic impacts, geological condition, construction cost, construction method, social and environmental impacts, etc. Thus, it was necessary to conduct several trials to arrange the alignment to reflect alternative station locations and types related to these conditions.

In particular, it has to be decided how to deal with the control points for planning an alignment.

The major control points are as shown in Figure 4-8.



Source: JICA Study Team

Figure 4-8 Existing Control Points

The basic criteria for alignment planning and station arrangement are as follows:

- How useful and/or convenient for passengers?
- How can value be created for the city and/or citizens?
- How can cost be reduced?
- How can the social and environmental impact be reduced?

The above criteria are ranked in order of priority, but there must be balance among these criteria as well.

The top priority is to construct stations in highly convenient locations. Thus, some stations might be located in the vicinity of road junctions, but at the same time, may need to be deep below the ground. On the other hand, considering passenger convenience and reduced cost may dictate that stations be set in shallow positions below ground. Therefore, comprehensive planning regarding the alignment, track, structure, architecture, electrics/mechanics and construction is required.

The policy to be applied in setting the alignment may be outlined as follows:

- Avoid the foundation of existing structures as much as possible;
- Structures should be as close to ground level as possible;
- Gentle curves and gentle gradients should be applied as much as possible;
- Avoid passing through a residential area as much as possible;

- Minimize land acquisition;
- Locate stations within an interval of approximately 1 km from one another; and
- Alignment planning assumes the adoption of a single track w-tube style as the shape of the tunnel.

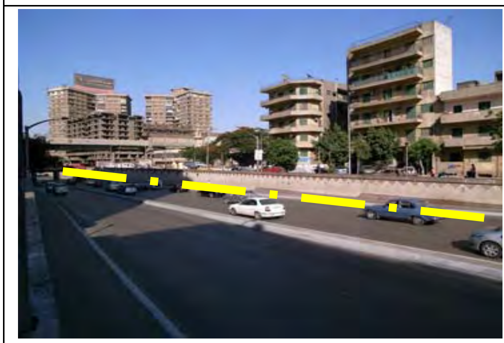
(3) Alignment Planning for Metro Line 4

Based on the above policy, the alignment and station location is decided on the basis of considering how best to overcome the control points.

Table 4-6 shows how the alignment should be established considering the control points.

Table 4-6 Considerations for Possible Alignment of Metro Line 4

Control Points	Considerations
El Malek El Saleh Line 1 Bridge & Underpass	To avoid the bridge and underpass road
	Metro Line 4 will pass through underground beside Salah Salem Street on the down grade. It will run beneath the buildings in the photo.
El Malek El Saleh Flyover	To avoid the foundation of the flyover
	Metro Line 4 will pass beneath the foundation piles of the flyover. Upon getting the information on the depth of the foundation, it might be possible to construct the tunnel at a shallow depth rather than its present proposed depth.
Nile Branch & El Malek As-Salik Bridge	To avoid the foundation of the bridge
	To divert the foundation of the bridge below the river bed.
El Rauda	To reduce resettlement
	Metro Line 4 will run under the road for almost its entire length. On the other hand, it has to avoid the foundation of El Giza Bridge. Therefore, the alignment has to shift to the right side of the abutment. The station structure will also shift to this side. Metro Line 4 will pass beneath some obstacle buildings. Nevertheless, it has to avoid the mosque.

Control Points	Considerations
Nile River & El Giza Bridge	To avoid the foundation of the bridge
	Metro Line 4 will pass beneath the riverbed to avoid the foundation of the bridge. If Metro Line 4 would pass beneath the foundations of the bridge, the tunnel has to veer deeper.
Giza Square Flyover	To avoid the foundation of the flyover
	Metro Line 4 will run underground along this road between the buildings and the flyover avoiding foundations as much as possible. Thus, it is considered that the alignment should have the form of two vertically parallel single tubes. The station will be located near here and will be unavoidably near the flyover foundation. Thus, it will be necessary to underpin and/or temporarily close this flyover during the construction.
ENR Bridge & El Giza underpass	To avoid the foundation of the existing bridges
	Road traffic in this place is very congested all through the day. It will be difficult to close this section even temporarily during the construction. Thus, Metro Line 4 will run along the near side of the wall which is the station side.

<table>
<tr><th>Control Points</th><th>Considerations</th></tr>
<tr><td>Metro Line 2 Bridge</td><td>To avoid the foundation of the bridge</td></tr>
<tr><td>
</td><td>The beam of Metro Line 2 has a wide span. Metro Line 4 tunnel can avoid the bridge foundations within this span. On the other hand, ENR bridge has approximately only 15 m span. Its foundation has some pre-cast concrete piles with a length of approximately 10 m.</td></tr>
<tr><td>Zomor Canal</td><td>To avoid the canal</td></tr>
<tr><td></td><td>Zomor Canal has been restored by providing a culvert at this section. However, the former bridge still remains now. Therefore, Metro Line 4 has to pass beneath the bed of the canal and the foundation of the bridge.</td></tr>
<tr><td>Ring Road Bridge</td><td>To avoid the foundation of the bridge</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Mariouteyah Canal</td><td>To avoid the canal</td></tr>
<tr><td></td><td>Mariouteyah Canal is running across and under the bridge on the road. Therefore, Metro Line 4 has to pass beneath the bed of the canal and the foundations of the bridge.</td></tr>
</table>

Control Points	Considerations
Mariouteyah Tunnel	To avoid the underpass
	This place was an old canal and was converted into a road. However, the former bridge still remains now. Therefore, Metro Line 4 has to pass beneath the foundation of the bridge.
Mansoureyah Canal	To avoid the canal
	Mansoureyah Canal is running across and under the bridge on the road. Therefore, Metro Line 4 has to pass beneath the bed of the canal and the foundations of the bridge.

Source: JICA Study Team

The result of the alignment planning is shown in Table 4-7.

Outline drawings of the alignment are shown in Figure 4-9.

Table 4-7 Data of the Alignment

Station Number		kilometerage (m)	altitude (m)	Curve Parameter (West Line) Radius (m)	Grade (‰)	Vertical Curve	Article of alignment
Station No.1	El Malek El Saleh	0	−8.4	0	0	−	
		237	−8.4	0	−10	3000	/To down to underpassing underneath of Nile Branch
		376	↓	−400	−10	−	/To shift to below Salah Salem St.
		424	↓	0	−10	−	after avoided the abutment
		521	↓	1000	−10	−	
		597	−12.0	1000	0	3000	
Station No.2	El Rauda	732	−12.0	1000	0	−	/To avoid the abutment of Giza Bridge
		827	−12.0	0	0	−	
		936	−12.0	0	3.5	3000	/To up to the above story on the east line's one
		1,011	↑	−1000	3.5	−	/To shift to below Salah Salem St.
		1,364	−10.5	−1000	0	3000	
		1,448	−10.5	0	0	−	
		1,524	−10.5	400	0	−	/To turn to the parallel direction of Salah Salem St.
		1,567	−10.5	0	0	−	
		1,737	−10.5	−1000	0	−	/To shift to the side road avoided the flyover
Station No.3	El Nile	1,743	−10.5	−1000	0	−	
		1,796	−10.5	0	0	−	
		1,932	−10.5	0	12	3000	/To up for adjusting the platform level of Giza Sta.
		2,049	↑	−250	12	−	/To turn along Salah Salem St.
		2,228	↑	0	12	−	
		2,302	↑	750	12	−	/To turn along Pyramids Rd.
		2,390	−5.0	750	0	3000	
		2,603	−5.0	1400	0	−	/To turn for avoiding the foundations of ENR line's bridge
Station No.4	El Giza	2,734	−5.0	1400	0	−	
		2,823	−5.0	0	0	3000	/To undrpass underneath of Zomor Canal
		2,882	−5.0	0	13	3000	/To up as possible as shallow
		3,536	3.5	0	0	3000	
Station No.5		3,815	3.5	0	0	−	
		4,287	3.5	0	−25	3000	/To down to B3 level
		4,567	−3.5	0	0	3000	
Station No.6		4,705	−3.5	0	0	−	
Station No.7		5,595	−3.5	0	0	−	
Station No.8		6,545	−3.5	0	0	−	
		6,679	−3.5	0	10	3000	/To up as possible as shallow
		7,379	3.5	0	0	3000	
Station No.9		7,495	3.5	0	0	−	
		7,913	3.5	0	−30	3000	/To down for underpassing underneath of Mariouteyah Canal
		8,230	−6.0	0	0	3000	
Station No.10		8,400	−6.0	0	0	−	
Station No.11		9,358	−6.0	0	0	−	/To undrpass underneath of Mansoureyah Canal
		9,473	−6.0	−1000	0	−	/To shift to the left side of PRAMIDS Rd.
		9,533	−6.0	0	0	−	
		9,612	−6.0	1000	0	−	/To turn to the parallel direction of PYRAMIDS Rd.
		9,657	−6.0	0	0	−	
		9,871	−6.0	250	0	−	/To turn toward Alexsandria Desert Rd.
		9,982	−6.0	250	12	4000	passing through underneath of the resident area
		10,178	↑	0	12	−	/To up for adjusting the platform level of Remayah Sta.
		10,290	↑	−300	12	−	/To turn along Alexsandria Desert Rd.
		10,392	↑	0	12	−	
		10,482	0.0	0	0	3000	
Station No.12	El Remayah	10,590	0.0	0	0	−	
		10,727	0.0	−250	0	−	/To turn toward Fayoum Rd.
		11,033	0.0	0	0	−	
		11,134	0.0	0	35	3000	/To up as possible as shallow
		11,268	↑	250	35	−	/To turn toward El Remayah St.
		11,649	↑	0	35	−	
		12,009	↑	1000	35	−	/To turn along El Remayah St.
		12,054	↑	0	35	−	/To up as possible as shallow
		12,162	36.0	0	0	3000	
Station No.13	GEM	12,300	36.0	0	0	−	
		12,434	36.0	0	18	3000	/To up as possible as shallow
		12,535	↑	−250	18	−	/To turn along the boundary of military area
		12,803	↑	0	18	−	passing through underneath of the resident area
		12,921	↑	−400	18	−	/To turn along the boundary of military area
		13,043	↑	0	18	−	
		13,342	↑	600	18	−	/To turn along the boundary of military area
		13,490	55.0	600	0	4000	
		13,603	55.0	0	0	−	
Station No.14	Hedaeck Al Ahram	13,885	55.0	0	0	−	
		14,025	55.0	400	0	−	/To turn for across the military area
		14,150	55.0	400	30	4000	/To up for adjusting transformation of the surface level
		14,341	↑	0	30	−	
		14,417	63.0	0	0	3000	
		14,578	63.0	0	−25	3000	/To down for adjusting transformation of the surface level
		15,098	50.0	0	0	3000	
		15,190	50.0	0	25	3000	
		15,282	↑	−250	25	−	/To turn toward Southern along Ring Rd.
		15,670	62.0	−250	0	4000	
		15,770	62.0	0	0	−	
Station No.15	Terminal	16,138	62.0	0	0	0	
				(−) means left curve	(−) means down curve		

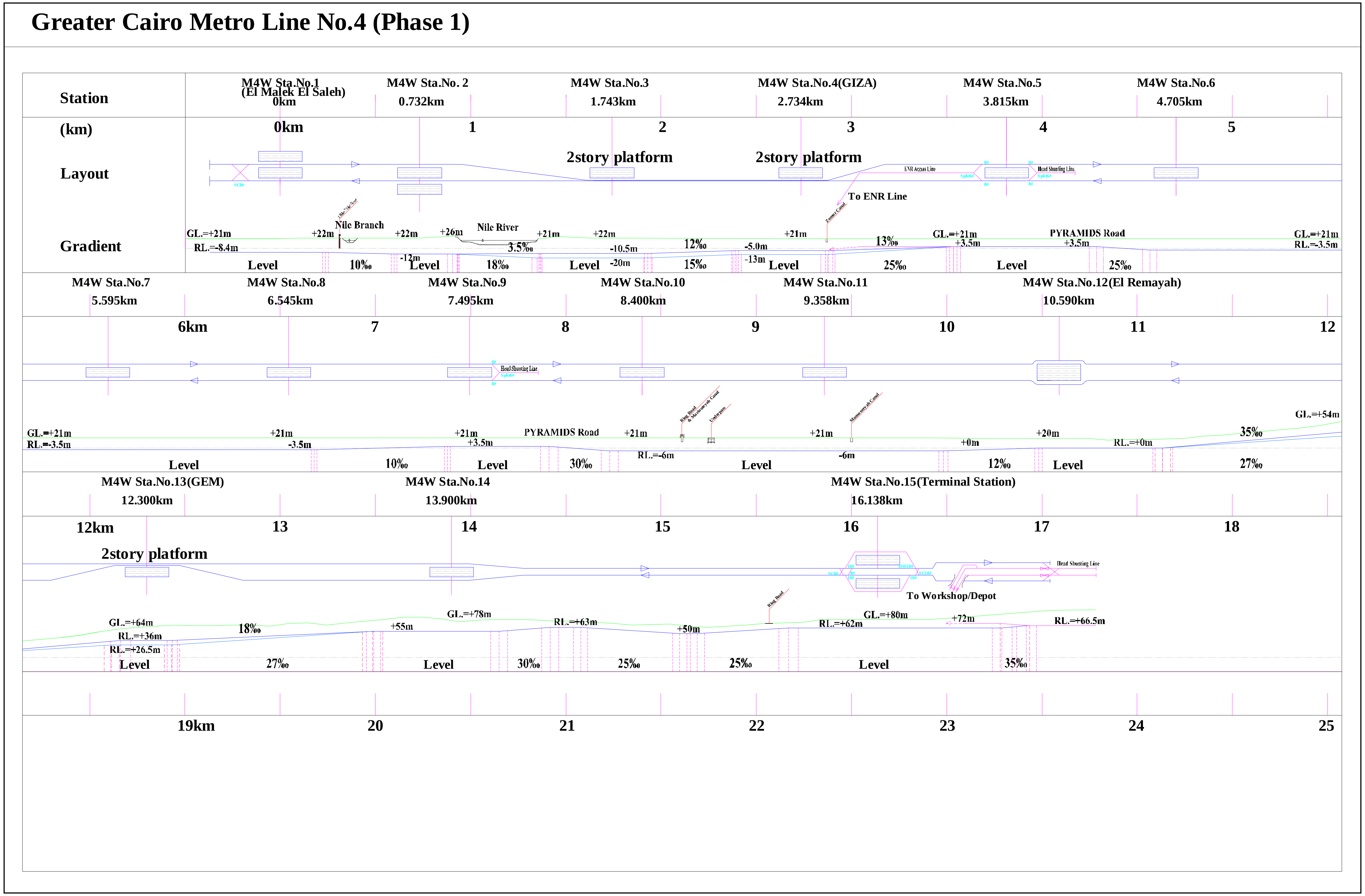
Source: JICA Study Team

(4) Outline of Alignment and Station Location

An outline of the plan view and station location is shown in Figure 4-9. The schematic plan and profile are shown in Figure 4-10.

Source: JICA Study Team

Figure 4-9 Outline of Alignment for Phase 1



Source: JICA Study Team

Figure 4-10 Schematic Plan and Profile

(5) Station Arrangement and Track Layout

1) Outline of Planning

The proposed station plan is summarised in Table 4-8 below.

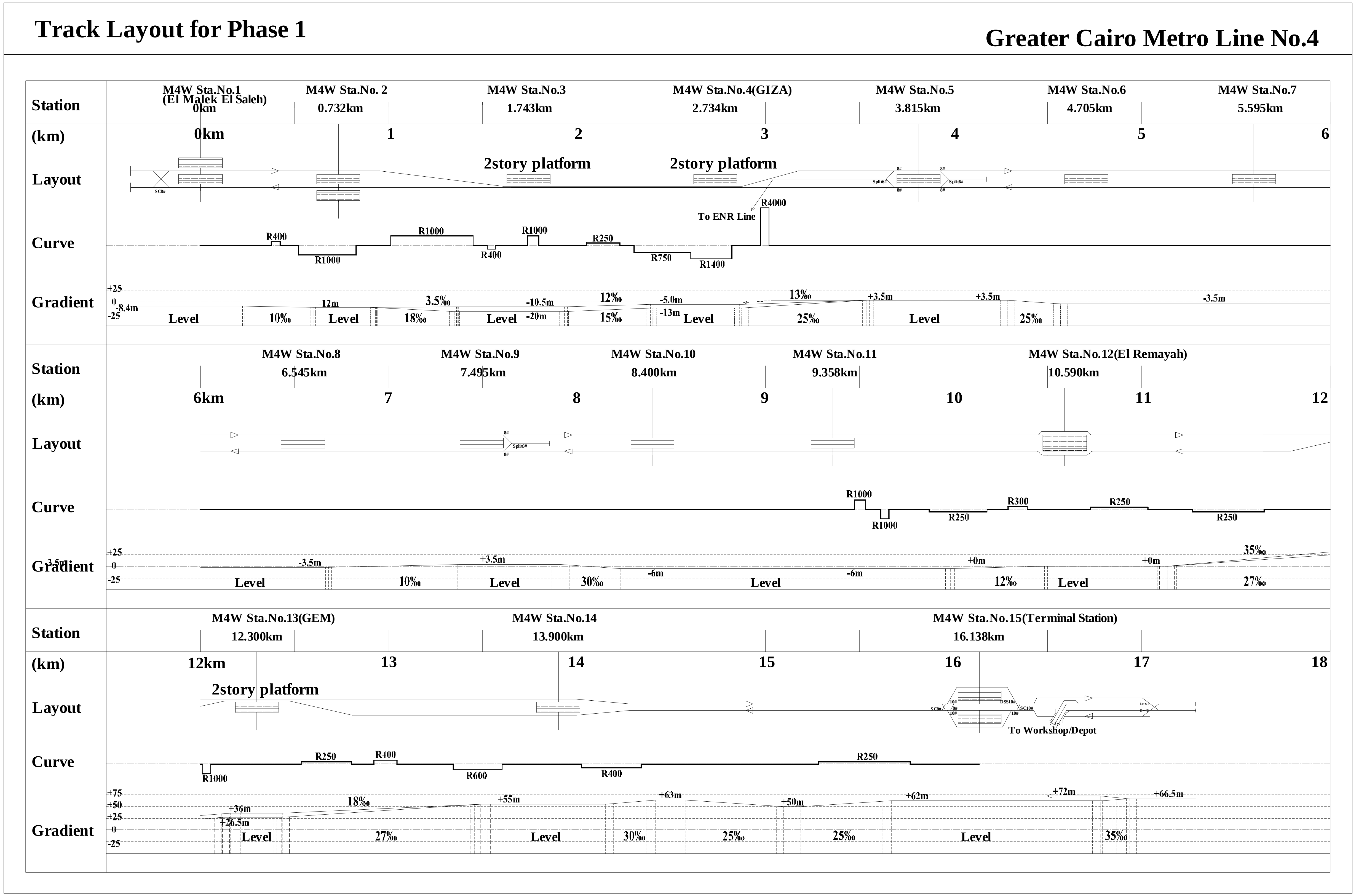
Table 4-8 Station Location

Phase1						
No.	Station	kilometerage		Platform Type	Article
		km	km		
1	M4W-Station No.1				Sciessor crossing for shuttling
	(El Malek El Saleh)	0.00		Island + Separate	2 stabling lines
2	M4W-Station No.2		0.73		
	(El Rauda)	0.73		Separate	
3	M4W-Station No.3		1.01		
	(El Nile)	1.74		2Stories separate	
4	M4W-Station No.4		0.99		
	(El Giza)	2.73		2Stories separate	
5	M4W-Station No.5		1.08		ENR connecting line
		3.82		Island	Head shunting line
6	M4W-Station No.6		0.89		
		4.71		Island	
7	M4W-Station No.7		0.89		
		5.60		Island	
8	M4W-Station No.8		0.95		
		6.55		Island	
9	M4W-Station No.9		0.95		
		7.50		Island	Head shunting line
10	M4W-Station No.10		0.91		
		8.40		Island	
11	M4W-Station No.11		0.96		
		9.36		Island	
12	M4W-Station No.12		1.23		
	(El Remayah)	10.59		Island	
13	M4W-Station No.13		1.71		
	(GEM)	12.30		2Stories separate	
14	M4W-Station No.14		1.59		
		13.89		Island	
15	M4W-Station No.15		2.25		
		16.14		2 Islands	W/D connecting line
		Total	16.14		

Source: JICA Study Team

The interval between stations is generally 1 km in the central city area according to the basic policy. The platform type is selected based on actual conditions. It is described in detail in the following section.

The schematic track layout is as shown in Figure 4-11.



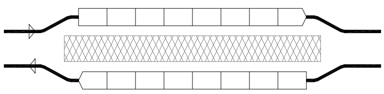
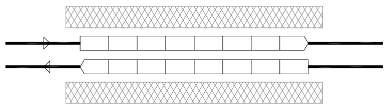
Source: JICA Study Team

Figure 4-11 Schematic Track Layout

2) Platform Type

Two platform types have been applied to this project. One of them is known as the “island” type. This type of platform is located between two mainlines. The other is known as the “separate” type which is a platform located beside each mainline. The character of both types can be observed in Table 4-9.

Table 4-9 Types of Platform

	Island Type	Separate Type
		
Advantage	Generally, total platform width will be minimized with same furnishings because passengers bound for both directions will share a single escalator. Also, it will be easier for passengers to select the platform	It will involve simple straight track arrangement. It will involve less passenger congestion, even if trains in both directions arrive at the same time.
Disadvantage	It will require expansion of the distance between the mainlines.	Twice the number of escalators and/or elevators will be required compared to the island type.

Source: JICA Study Team

A w-tube single track style is proposed for the tunnel sections of this project. In this type of route arrangement, diverted tracks beside an island platform can be provided easily. Thus, it is proposed that the island type platform should be adopted as the standard type for Metro Line 4.

3) Track Layout

The following will be the main requirements for the track layout:

Starting station has to have shuttling facilities, namely: turnouts, head shunting line, etc.

If it is possible, the final station has to be arranged in four lines and double platforms, owing to the need to connect to the workshop/depot behind the station. Such an arrangement will also be beneficial for the future operation and extension of the route.

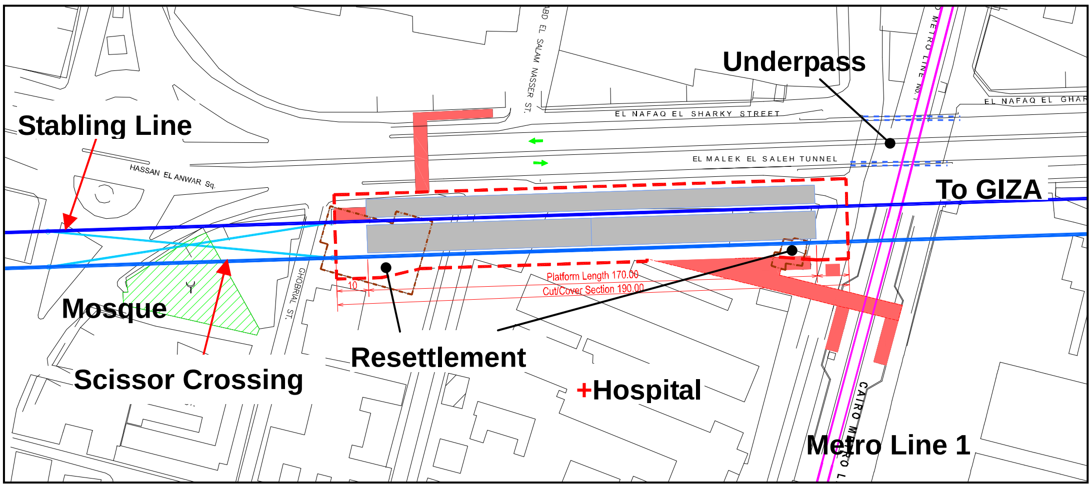
Head shunting lines are required at intervals of approximately 5 km to provide for emergency operations and/or for the maintenance of permanent way.

4) Detailed Description of Track Layout

a) M4W Station No. 1 <El Malek El Saleh>

Station Character

El Malek El Saleh Station is the beginning station for Phase 1. Thus, Metro Line 4 will be operated by shuttling from this station until the start of operation of the Phase 2 section. This will require provision of two stabling lines behind the platform and some turnouts for shuttling. Since this station will be connected with Metro Line 1, it will be important to provide a simple easy-to-understand platform layout with enough space for the transfer passengers.



Source: JICA Study Team

Figure 4-12 Proposed Plan View of Station No. 1

Platform Arrangement and Track Layout

This station location is decided for two main reasons. The first of these is that resettlement and land acquisition will be minimized at this location and the second is that it will avoid demolishing the existing underpass crossing beneath Metro Line 1 on Salah Salem Street. Thus, this station extends below the roadside of the underpass and the garden of the hospital adjoining the road. There will be a need to resettle some shops and an orphanage building adjoining the hospital. Nevertheless, it is possible to apply the cut-and-cover method within an area of approximately 190 m by 25 m only.

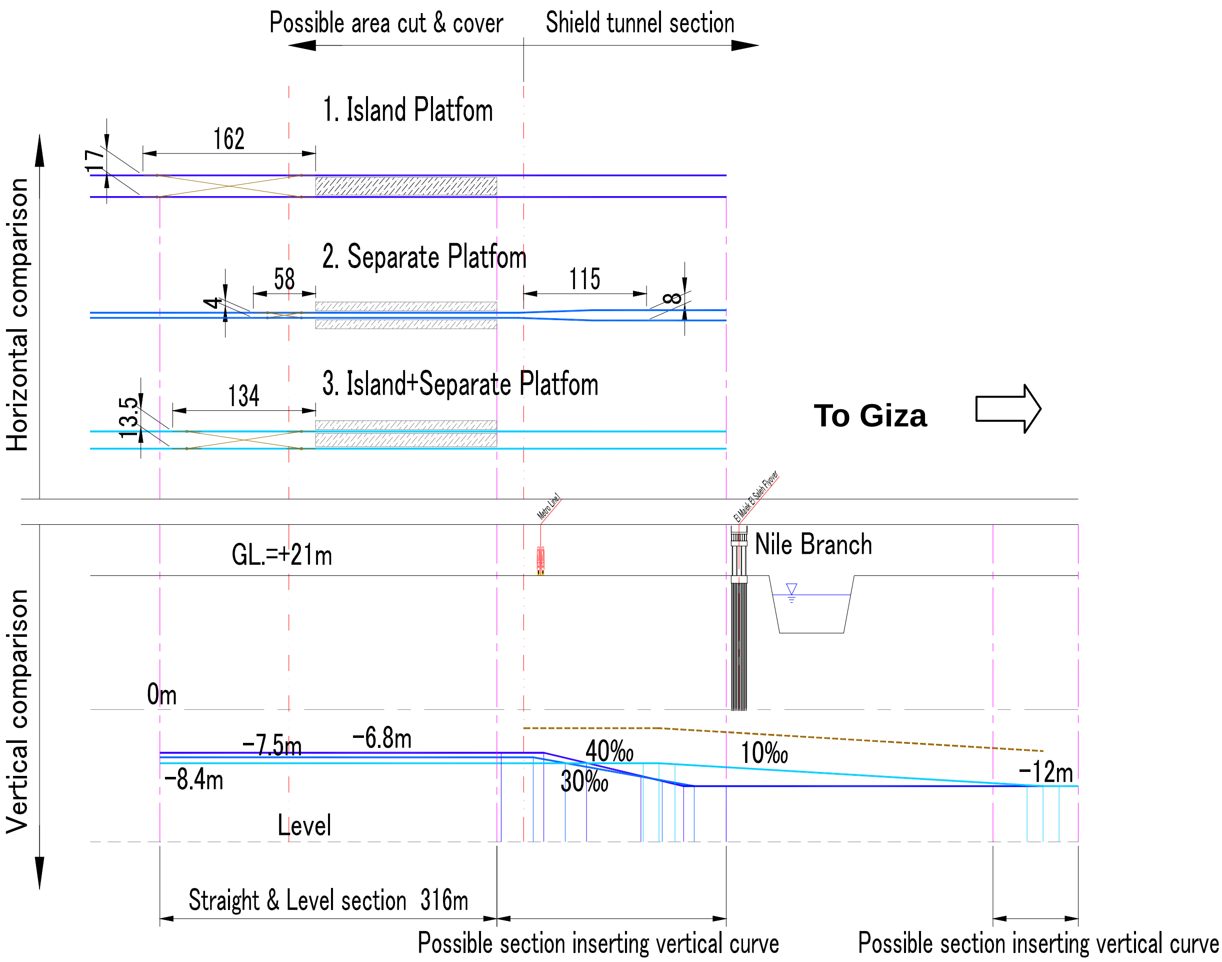
Surrounding Shops

Orphanage Building

On the other hand, from the viewpoint of track layout, Metro Line 4 has to pass beneath the foundations of the El Malek El Saleh Flyover and the Nile branch. These are the critical points for the alignment planning, which determine the area in which a gradient and a vertical curve of sufficient length can be provided at this location (see Figure 4-13 for further explanation). It is preferable for the line to be placed as near as possible to the ground level for the convenience of transfer passengers. Under these conditions, two alternatives are possible, each with a difference in track level of less than 2 m. There is no difference between these alternatives in terms of the number of storeys of the station structure. Therefore, it is preferable to select the alternative with the gentlest grade (refer to Figure 4-13).

The turnout layout for shuttling may be planned in one of two main ways. One way is to set a turnout before the platform. Another is to set it after the platform. Even if the turnout is before the platform, it will be necessary to provide a scissors crossing beyond the platform. This would be done for reasons of coordinated operation and reduced cost. If the alternative of providing the scissors crossing before the platform is selected, construction of this crossing would be necessary outside of the station area, requiring deep excavation or special tunnelling method under Metro Line 1, at a substantial increase of cost.

In the case of the El Malek El Saleh Station, however, it will not be possible to construct a scissors crossing beyond the platform within the cut and cover section because a mosque provides an obstruction on the surface. Therefore, it will be necessary in this case to adopt a special trench-less method of tunnelling to provide a scissors crossing connection between the two main tunnels. The cost of this procedure will not be different from that of the cut and cover method.



Source: JICA Study Team

Figure 4-13 Parameter Study for the Track Layout of El Malek El Saleh Station

A comparative study of the platform types was necessary in case of setting a scissors crossing beyond the platform. The result is as shown in Table 4-10.

Table 4-10 Comparison Table on Platform Arrangement

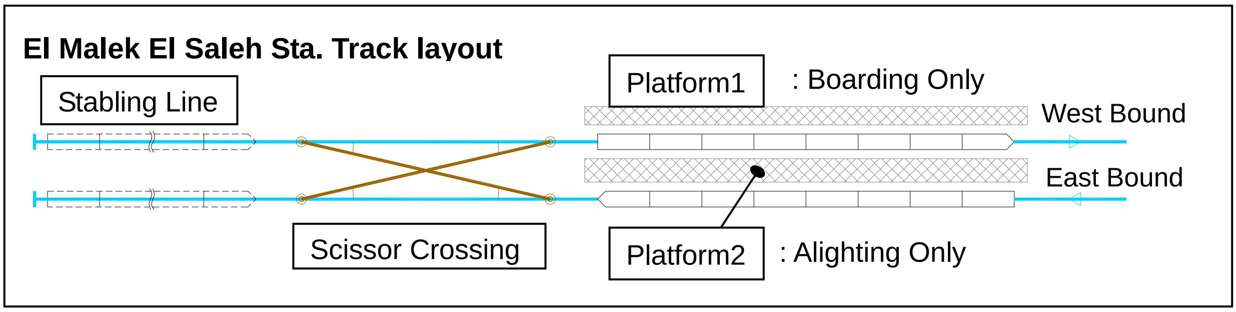
Platform Type	1. Island	2. Separate	3. Composite
Condition	• Platform length 170 m • Between shield tunnels minimum 8.0 m • Between tracks at a station 4.0 m • Possible square of cut & cover L: 220 m, W: 25 m • Straight and level section length including platform 316 m		
Platform width	14 m	9 m	9 m + 8 m
Scissors Crossing	L: 162 m W: 17 m	L: 58 m W: 4 m	L: 134 m W: 13.5 m
Advantage	All passengers can take trains in either direction from the same platform.	Length of scissors crossing will be minimized. It will divide the passengers by direction of travel and therefore reduce congestion.	Passengers can easily find the platform for trains travelling in their desired direction. It will divide the boarding and alighting passengers and therefore reduce congestion.
Disadvantage	Platform length plus scissors crossing length is over 316 m.	It needs to be excavated approximately 115 m before the platform.	Scissors crossing length is longer compared to that in the separate type.
Evaluation	Physically impossible	High cost	**Reasonable**

Source: JICA Study Team

Composite type aims to provide one separate platform in addition to an island platform. This type of platform can be expected to help avoid passenger congestion by separating boarding from alighting passengers during Phase 1. It will also provide more convenience from the perspective of passenger access.

The proposed track layout is shown in Figure 4-14 and is summarised below:

- Provision of one island platform plus one side platform: 2 platforms.
- Provision of one scissors crossing beyond the platform for shuttling operation.
- Provision of two stabling lines.



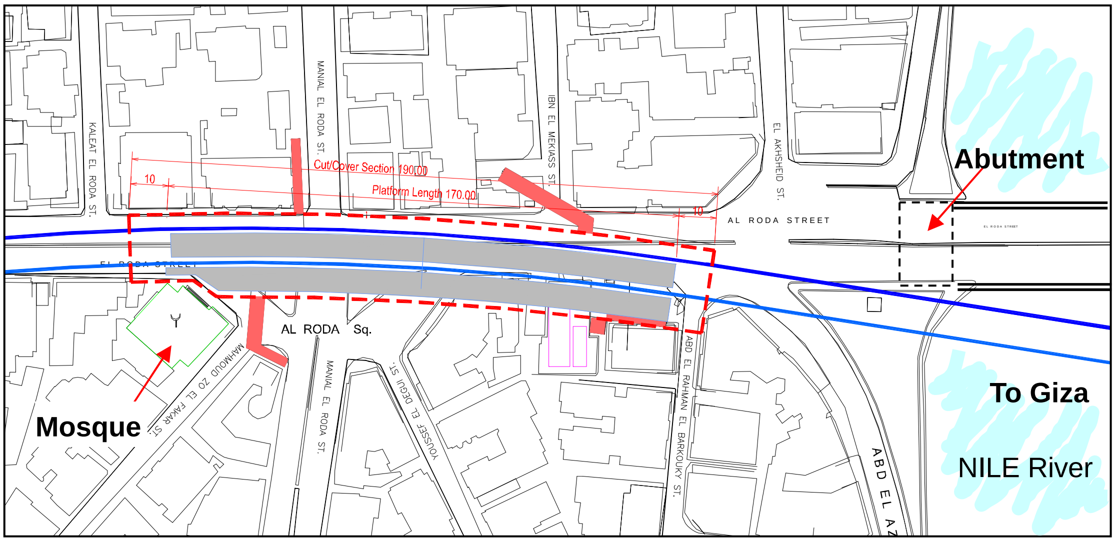
Source: JICA Study Team

Figure 4-14 Proposed Track Layout Plan for El Malek El Saleh Station

b) M4W Station No. 2 <El Rauda>

In this section, Metro Line 4 will run with a 1,000 m radius to avoid the foundation of the El Giza Bridge. The alignment is shifted from Salah Salem Street to the downstream side of the bridge. This station will be located in this curve section.

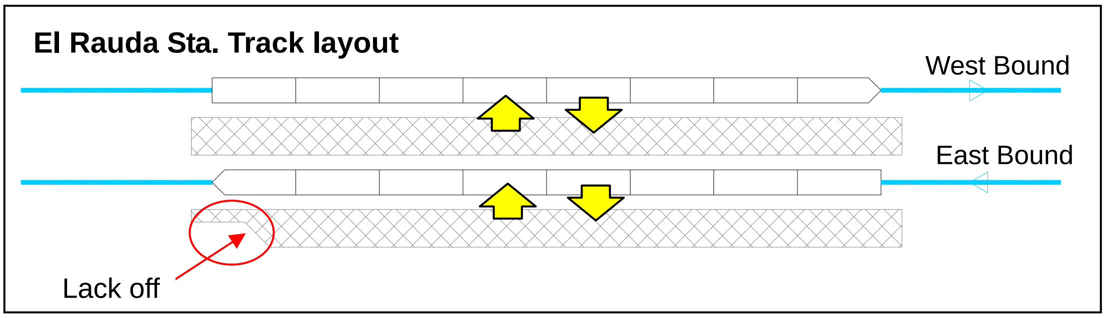
The platform arrangement is proposed as an irregular separate type, in order to minimize land acquisition and to avoid a mosque.



Source: JICA Study Team

Figure 4-15 Proposed Plan View of Station No. 2

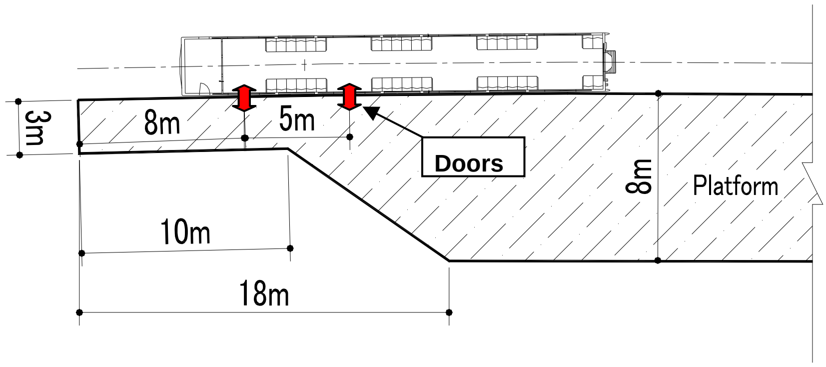
The proposed track layout is as shown in Figure 4-16.



Source: JICA Study Team

Figure 4-16 Proposed Track Layout Plan for Station No. 2

To avoid the demolition of a mosque, the left side of the east bound platform lacks width as shown in Figure 4-17. It will affect two doors of the first car for the boarding and alighting passengers. However, 3 m width can be kept in this part which will satisfy the regulation of platform width.



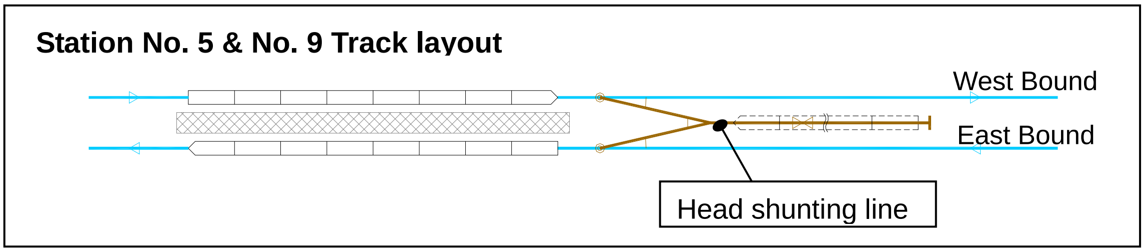
Source: JICA Study Team

Figure 4-17 Configuration of the Platform and Position of the Train Stop

c) M4W Stations No. 5 and No. 9

From the viewpoint of the operation plan, it is proposed to locate two Y-shaped tracks at Stations No. 5 and No. 9. These tracks will be used for temporary parking of troubled trains, and/or shunting of maintenance rolling stock, emergency shuttling, etc.

Further, the ENR access line is planned to branch from station No. 5. This line can also be used for shunting purposes. Thus, Station No. 5 will have the function of shuttling for both directions, as may be observed from Figure 4-18.

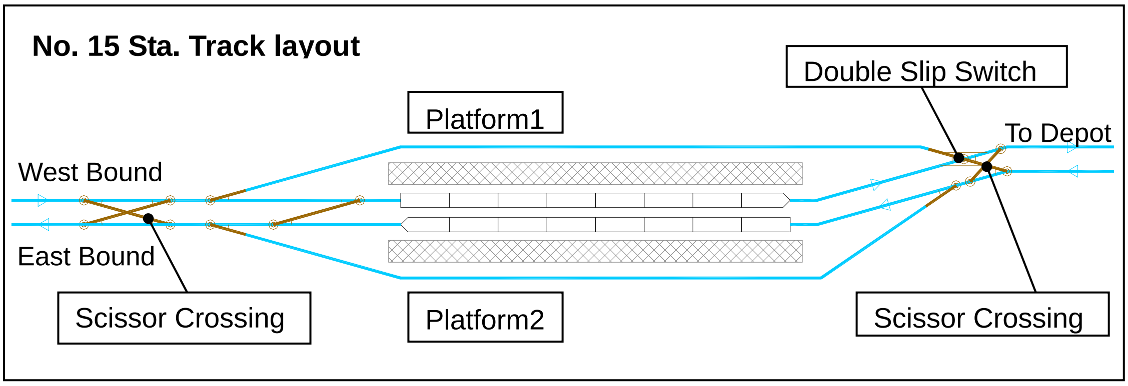


Source: JICA Study Team

Figure 4-18 Proposed Track Layout Plan for Stations No. 5 and No. 9

d) M4W Station No. 15

This station is the terminal station for Phase 1 and the connecting station with the workshop/depot line. Thus, it needs some function for shuttling and shunting to the depot. Therefore, it is desirable to arrange two platforms and four tracks at this location. The track layout will be designed such that all tracks can access each direction. Conversely, the design of the track layout will allow all trains coming from either direction to arrive at every platform.

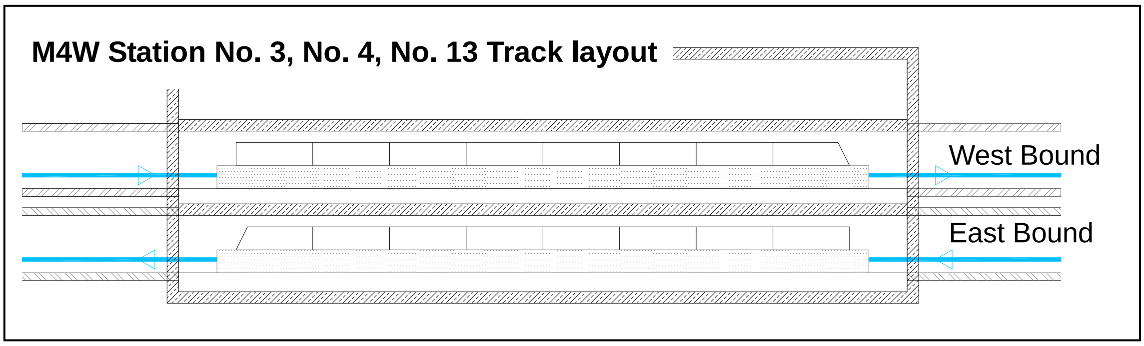


Source: JICA Study Team

Figure 4-19 Proposed Track Layout Plan for Station No. 15

e) M4W Station No. 3 <El Nile>, M4W Station No. 4 <El Giza>, M4W Station No. 13

These stations have two-storey platforms, each with a single track. There are no switches and/or crossings. Therefore, they are not critical points for alignment planning.

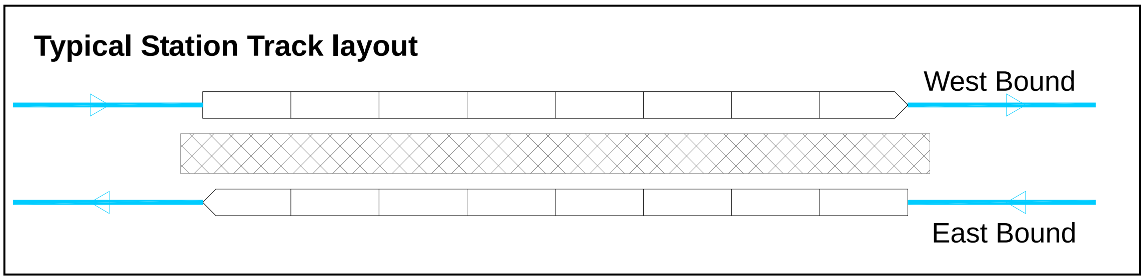


Source: JICA Study Team

Figure 4-20 Proposed Track Layout Plan for Station Nos. 3, 4, 13

f) Other Typical Stations

These stations have simple straight tracks and an island platform without switches and/or crossings. Therefore, they are not critical points for alignment planning.



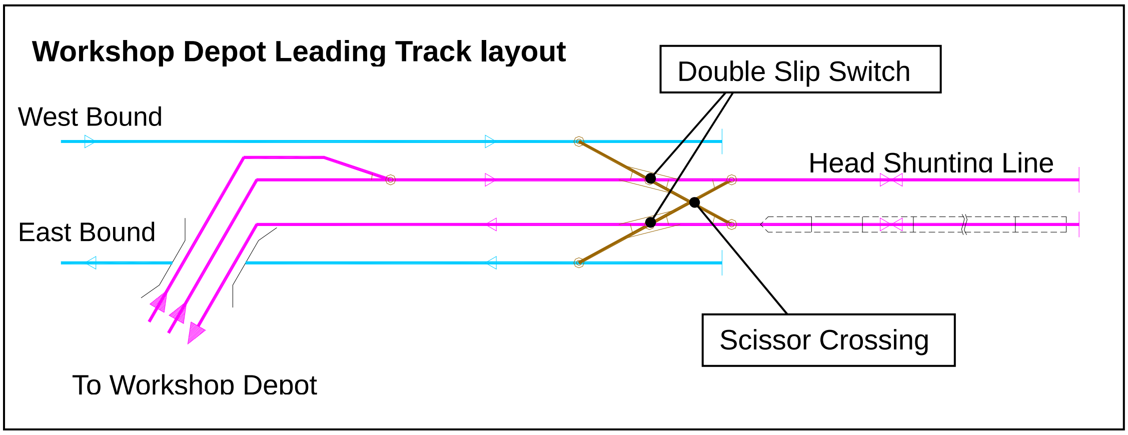
Source: JICA Study Team

Figure 4-21 Proposed Track Layout Plan for Typical Station

5) Leading Line to Workshop/Depot

There is a difference of more than 10 m between the track level of Station No. 15 and that of the Workshop/Depot (W/D). Trains entering the workshops will have to reverse from the end of the line at Station No. 15.

The proposed lead track layout which will allow this operation is as shown in Figure 4-22.



Source: JICA Study Team

Figure 4-22 Workshop/Depot Lead Track Layout Plan

This alignment is planned to position the lead line between the two mainlines in order to avoid a level crossing on the mainline. Further, if Metro Line 4 would be extended to 6th October City in the future, it is also possible to accommodate and dispatch trains from that direction without having to traverse a level crossing.

4.2 Train Operating Plan

4.2.1 Purpose

The purpose of the Train operating plan is to provide the necessary information for the E&M and operation and management plans, based on the traffic demand forecast, route alignment, and performance of rolling stock. The result of this study will provide the following information for the Phase 1 and Phase 2 sections:

- To estimate the minimum headway and provide the required performance for signalling system.
- To estimate the running time between terminals and calculate the required number of rolling stock.
- To estimate the annual train-kilometres and provide the annual working volume data required for the Operation & Maintenance Plan.

4.2.2 Key Operational Data and Parameters

Key operational data and parameters related to the Train operating plan and calculations resulting from this plan are summarized below. The results for Phase 2 are based on trial calculations.

Table 4-11 Key Operation Data and Parameters

Items	Phase 1 Section	Phase 2 Section
Total route length (double tracks) of the main line	16.1 km	17.6 km

Items	Phase 1 Section	Phase 2 Section
Track gauge (standard gauge)	1,435 mm	
Maximum gradient	40 ‰	
Minimum radius (main line)	250 m	
Number of stations Stations on the underground section Stations on the elevated section	 15 0	 12 4
Average distance between stations	1.15 km	1.10 km
Maximum speed Main Line (underground section) Main Line (elevated section) Inside the depot	80 km/hr 100 km/hr 25 km/hr	
Dwell time At intermediate stations	 30 seconds	
Round trip time For the Phase 1 section For Phase 1 + Phase 2	 70 minutes 137 minutes	
Average speed	32.2 km/hr	
Headways in peak hour In year 2020 (opening) In year 2050	 4 minutes 00 seconds 2 minutes 09 seconds	
Daily operation hours	05:00 - 01:00	
Number of trains (working day) In year 2020 (opening) In year 2050	 198 trains per direction 367 trains per direction	
Train composition In year 2020 (opening) In year 2050	 8 cars in a train-set 8 cars in a train-set	
Total number of train-sets (spares included) In year 2020 (opening) In year 2050	 20 train-sets 70 train-sets including that for Phase 2	
Train dimensions Car length (over coupler faces) Car width Car height Train-length (8 car unit)	 20.0 m 2.88 m 3.7 m 160 m	
Signal system Main Line (including stabling yard) Inside the depot	Cab signal (ATP with track circuit) Way side signal	
Traction power system	1,500 V, Catenary system	
Central control point (CCP)	At El Malek El Saleh Station	
Automatic fare collection (AFC)	Common system in Cairo commuter lines and ticket vending machine as option	

Source: JICA Study Team

4.2.3 Basic Policy for Train Operating Plan

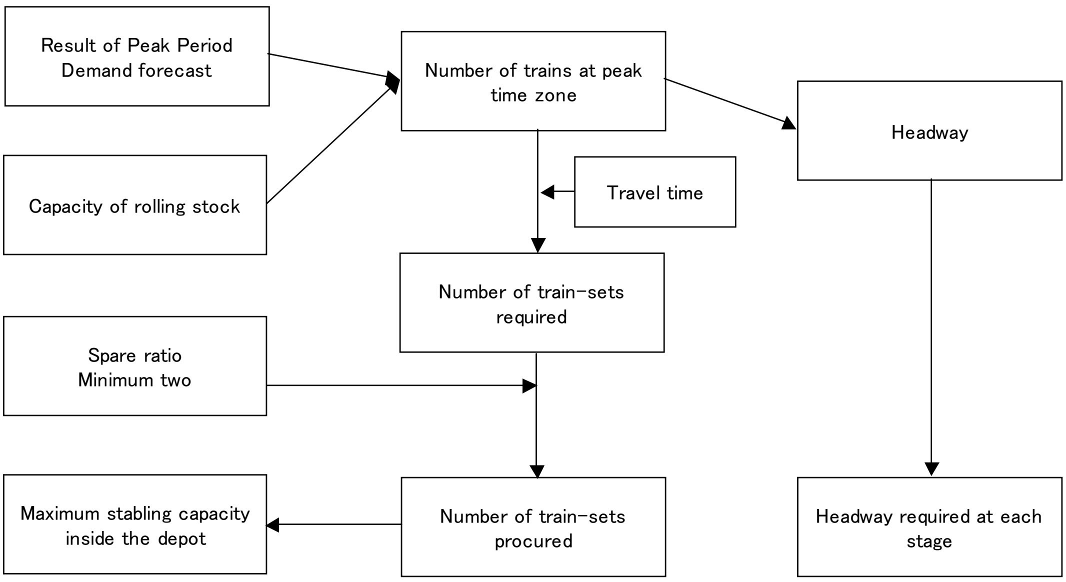
The outline of the methodology of the train operating plan and the meaning of peak hour transport, which is the core concept of the train operation plan, are mentioned below.

(1) Target Sections for Train Operating Plan

The target sections for the train operating plan comprise both the Phase 1 and Phase 2 sections. Regarding the Phase 2 section, two alternatives, a northern route and an eastern route, were initially considered. In this study, however, the northern route is assumed as the selected Phase 2 section, based on the decision of JICA Study Team. Due to delays in decisions about the exact alignment, some assumptions were applied for Phase 2. These results should be updated based on the more correct conditions identified in the further study.

(2) Input and Output Data of the Train Operating Plan

The train operating plan is prepared based on the workflow shown in Figure 4-23 below. As shown in the figure, the traffic demand forecast, rolling stock capacity, and running time become “input data”, and the required number of rolling stock, required minimum headway, which is used in the signalling system planning, and required capacity of the workshop/depot become “output data”. Running time is calculated based on the performance data of rolling stock and track alignment data in the Train Operating Plan.

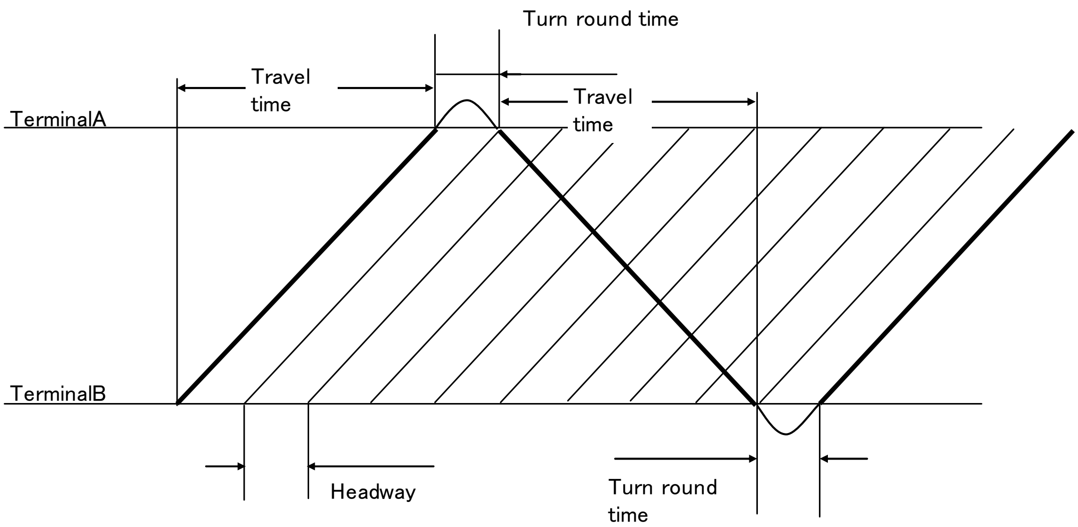


Source: JICA Study Team

Figure 4-23 Workflow of Train Operating Plan

(3) Demand in Peak Hour and the Required Number of Trains

The length of urban railways is generally short and trains can turn back in the opposite direction immediately after arriving at the terminal. Therefore, it is possible to cover the entire daily train operation with the number of train sets required during peak hour. Hence, the demand in the peak hour is the most important factor for calculating the required number of cars. The relationship between train operation during peak hour and the required number of trains is shown in Figure 4-24 below.



Source: JICA Study Team

Figure 4-24 Concept of Calculation Method for Required Number of Train Sets

4.2.4 Sectional Demand in Peak Hour

The sectional demand during peak hour estimated from the traffic demand forecast result is shown in Table 4-12 below.

Table 4-12 Sectional Passenger Demand during Peak Hour

Phase	Section	2020	2023	2027	2050
North Phase2	N-Sta.17- N-Sta.16	0	13,370	16,040	17,850
	N-Sta.16- N-Sta.15	0	18,740	20,590	25,170
	N-Sta.15- N-Sta.14	0	26,960	28,980	35,600
	N-Sta.14- N-Sta.13	0	29,320	31,890	38,540
	N-Sta.13- N-Sta.12	0	37,420	39,400	36,740
	N-Sta.12- N-Sta.11	0	40,910	43,650	44,490
	N-Sta.11- N-Sta.10	0	45,280	47,180	49,570
	N-Sta.10- N-Sta.9	0	47,020	49,670	52,090
	N-Sta.9- N-Sta.8	0	50,760	53,470	55,750
	N-Sta.8- N-Sta.7	0	38,720	40,010	42,770
	N-Sta.7- N-Sta.6	0	38,040	40,140	43,010
	N-Sta.6- N-Sta.5	0	16,740	26,680	36,550
	N-Sta.5-N-Sta.4	0	15,700	25,680	35,160

Phase	Section	2020	2023	2027	2050
	N-Sta.4- N-Sta.3	0	15,930	25,960	35,460
	N-Sta.3- N-Sta.2	0	15,120	25,190	34,360
	N-Sta.2- WN-Sta.1	0	16,290	25,190	34,360
Phase1	WN-Sta.1- W-Sta.2	15,600	19,280	26,780	32,280
	W-Sta.2- W-Sta.3	14,690	18,400	26,010	31,430
	W-Sta.3- W-Sta.4	18,750	22,600	30,390	36,900
	W-Sta.4- W-Sta.5	29,940	31,340	40,930	54,930
	W-Sta.5- W-Sta.6	29,490	30,870	40,310	54,100
	W-Sta.6-W-Sta.7	27,220	28,590	39,960	53,630
	W-Sta.7- W-Sta.8	21,110	22,020	39,280	52,830
	W-Sta.8- W-Sta.9	20,570	21,460	38,300	51,510
	W-Sta.9- W-Sta.10	16,840	17,750	35,870	48,870
	W-Sta.10 - W-Sta.11	12,180	12,870	32,570	44,370
	W-Sta.11- W-Sta.12	9,570	10,260	30,580	41,510
	W-Sta.12-W-Sta.13	6,450	7,040	28,080	38,680
	W-Sta.13-W-Sta.14	3,560	3,990	25,730	31,880
	W-Sta.14-W-Sta.15	1,940	2,280	23,550	28,150

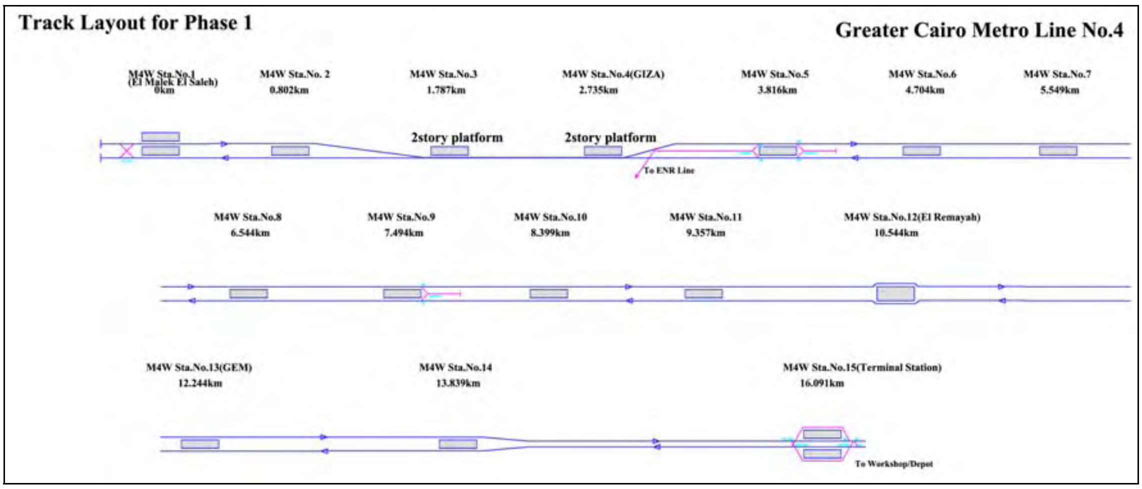
Source: JICA Study team

4.2.5 Track Layout Plan for the Main Stations

The track layout plan for the main stations is reviewed from the viewpoint of the transportation plan, as shown below, for the following purposes:

- To realize the required train operation such as minimum headway, etc.;
- To ensure convenience for passengers; and
- To install the facilities to deal with disrupted operation and to provide refuge tracks for a troubled train away from the main lines.

The reviewed track layout of the Phase 1 section is shown in Figure 4-25. The process of the review is mentioned below.



Source: JICA Study Team

Figure 4-25 Track Layout of the Phase 1 Section

(1) Basic Train Operating Plan (Phase 1 Section)

1) Exclusive Operation of Stopping Train

The purpose of operating the Phase 1 section is to provide a short transit route to the city. Many people are living along the line, and as shown in Table 4-12, all stations have a lot of passengers. Therefore, in the Phase 1 section, all trains should stop at every station. A rapid service operation will not be viable.

2) No Turn-back Operation at Intermediate Stations for Normal Operation

The length of Phase 1 section is comparatively short (16.1 km), and there is no large demand difference among the stations. Therefore, it is recommended not to conduct turn-back operations at intermediate stations during normal operation, except for the first and last trains staying at intermediate stations overnight.

3) Installation of Turn-back Equipment at Some Intermediate Stations for Troubles

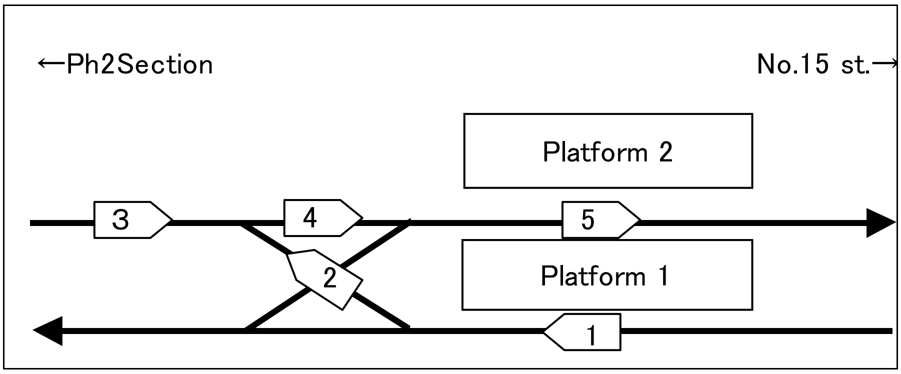
The more the number of stations with turn-back equipment, the more convenient it is for transportation. In consideration of the cost, it is proposed to install the equipment at every 4 to 6 stations. Refuge tracks for troubled trains will be installed at the same interval.

(2) WN-Sta.1 Station (El Malek El Saleh)

1) Turn-back Time and Headway

The station will be the terminal for turn-back operation until the Phase 2 section starts its operation (assumed in 2023). The minimum headway should be 4 minutes 00 seconds according to Table 4-18.

Then, actual turn-back time of a train is estimated at 420 seconds, as shown in Table 4-13. The station has two stabling tracks for turn-back operation, and it means the minimum possible headway is 3 minutes 30 seconds (210 seconds = 420 seconds/2). Hence, the minimum possible headway (3 minutes 30 seconds) is shorter than the required minimum headway (4 minutes 00 seconds) making it possible to deal with the turn-back operation until 2023. In addition, it is possible to reduce the turn-back time to 270 seconds if another driver gets on the rear end cab in advance at the station.



Source: JICA Study Team

Figure 4-26 Track Layout for Station WN-Sta.1

Table 4-13 Turn-back Time per Train

Step	Work Item	Time (seconds)
1	Dwell time after arrival	45
2	Running time to stabling track	60
3	Driver's moving time to back end cab.	210 (60)
4	Running time to departure platform	60
5	Dwell time before departure	45
	Total	420 (270)

Note: i) number in ( ) means the time when another driver gets on the back-end cab in advance.

ii) At this station, scissors turnouts are installed at the back-end of the terminal

Source: JICA Study Team

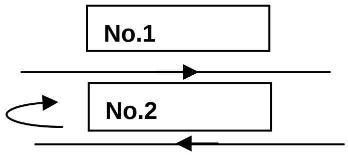
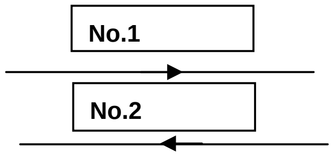
An extra section, which becomes a part of Phase 2 section in the future, will be installed at the back-end of the station. The tracks can be used as stabling tracks and/or refuge track for troubled trains.

2) Type of Platform

The platform arrangement should be planned and designed such that passengers can reach their train without mistake. Due to the limitation of the construction method, the platform cannot be arranged as a "side platform". In addition, an island platform cannot provide enough width to deal with the passengers. Therefore, a hybrid platform layout should be applied as shown in Figure 4-26. The station is the "terminal" before 2023 (expected start year of Phase 2 operation) and will be transformed to an intermediate station after 2023.

Because the turn-back facility for the station is installed at the Phase 2 side, the same platforms will be used for each train direction (No. 1 platform for down line and No. 2 platform for up line) both before and after Phase 2 operation. It is easy for the passengers due to the unification of platforms for both train directions.

Table 4-14 Type of Platform and Arrival and Departure of Train

Term	Type of Station	Usage of Platform	
Before 2023	Terminal		The train is turned at the turn-back facility at Phase 2 side, same platforms are used for each direction (No. 1 platform for down line and No. 2 platform for up line)
After 2023	Intermediate station		Down line trains will use No. 1 platform and up line trains will use No. 2 platform.

Source: JICA Study team

(3) W-Sta. 5 Station

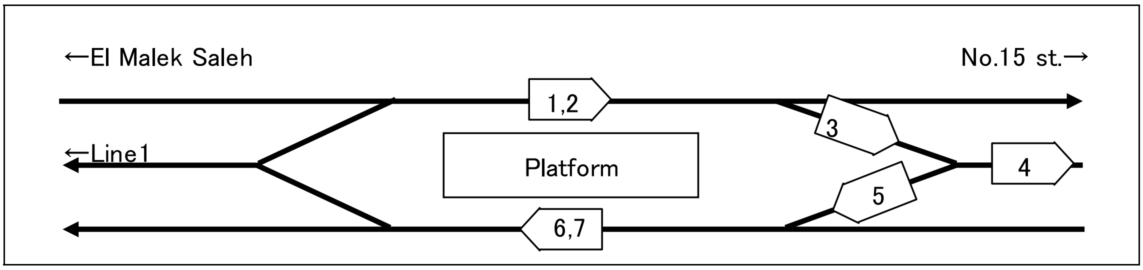
1) Connecting Line with ENR

In order to bring the rolling stock for Metro Line 4, a connecting line with ENR will be provided near Station W-Sta. 5. However, the connecting line will be used only at the commencement of Metro Line 4. In order to reduce the project cost, an alternative plan can be considered whereby the rolling stock for Metro Line 4 will be brought directly by trailers on road from a port, thereby avoiding the need for a connecting line.

2) Turn-back Facility during Troubles and Stabling of Troubled Train

Turn-back operation at intermediate stations should be considered in cases where the train cannot be operated due to troubles of rail, traction system, signalling system, etc. For this purpose, turn-back facilities are provided at Station W-Sta. 5, and W-Sta. 9 on Phase 1 section. The more the number of stations with turn-back facility, the more convenient it is to handle various trouble cases. On the other hand, it is not reasonable to put the facility at so many stations because it will cause an increase of the construction cost and maintenance work.

At W-Sta. 5, turn-back facilities will be provided at both ends of the station. For turn-back operation directed to El Malek El Saleh, it takes 420 seconds if the turn-back operation is carried out at the right end of the station in Figure 4-27 (Please see Figure 4-27 and Pattern A of Table 4-15). If the turn-back operation directed to El Malek El Saleh is carried out at the left end of Figure 4-27, it takes 750 seconds (please see Pattern B of Table 4-15). It is obvious that Pattern B will need more time than Pattern A since the latter case needs more number of driver cabin changes. Therefore, the turn-back facility is installed at both sides of the station.



Source: JICA Study Team

Figure 4-27 Track Layout for Station W-Sta. 5 and Turn-back Sequence (In case of Turn-back to Station W-Sta. 15)

Table 4-15 Turn back Time at Station W-Sta. 5 (In case of Using Turn-back Facility Located at the end of Station W-Sta. 15)

(unit: seconds)

Pattern			A	B
Turn-back operation work	1	Driver's moving time to back-end cab	-	210 (60)
	2	Dwell time after arrival	45	Included in "Driver's moving time to back-end cab"
	3	Running time to stabling track	60	60
	4	Driver's moving time to back-end cab	210 (60)	210 (60)
	5	Running time to departure platform	60	60
	6	Driver's moving time to back-end cab	-	210 (60)
	7	Dwell time before departure	45	Included in "Driver's move to back-end cab."
Total			420 (270)	750 (300)

Note: (i) Number in ( ) means the time in case another driver gets on the back-end cab in advance.

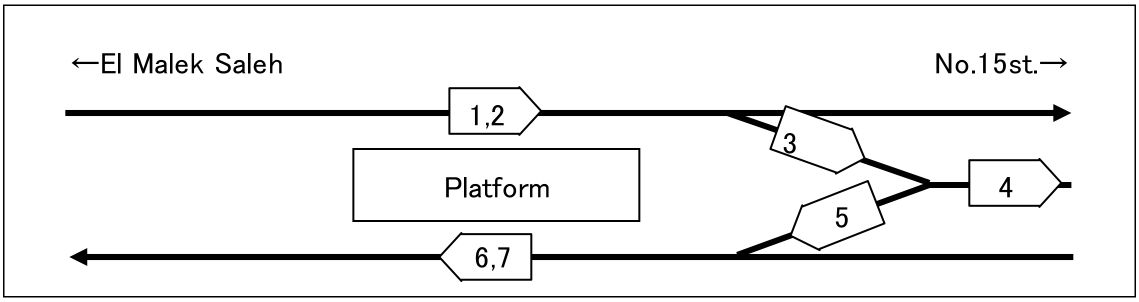
(ii) For details of running time from/to pool track, see Table 4-17.

Source: JICA Study Team

The turn-back facility can be used as a refuge track for troubled trains.

(4) W-Sta. 9 Station

As mentioned in Section (3).2) above, a turn-back facility is installed at Station W-Sta. 9 for partial operation due to some trouble and/or temporary stabling of a troubled train. From the viewpoint of train operation, it is better to put the turn-back facility on both sides of the station. However, it is not reasonable to spend a lot of construction cost against the infrequent use of this facility. Therefore, the facility is planned by putting greater importance on partial operation from/to El Malek El Saleh which is close to the centre of the city. The associated turn-back time is shown in Table 4-16.



Source: JICA Study Team

Figure 4-28 Track Layout for Station W-Sta. 9 and Turn-back Facility

Table 4-16 Turn-back Time for Station

(unit: seconds)

Pattern			A	B
Train		Origin station of the arriving train	Station WN-Sta. 1 (El Malek El Saleh)	Station W-Sta. 15
		Destination after turn-back operation work	Station WN-Sta. 1 (El Malek El Saleh)	Station W-Sta. 15
Turn-back operation work	1	Driver's moving time to back-end cab	-	210 (60)
	2	Dwell time after arrival	45	Included in "Driver's moving time to back-end cab"
	3	Running time to stabling track	60	60
	4	Driver's moving time to back-end cab	210 (60)	210 (60)
	5	Running time to departure platform	60	60
	6	Driver's moving time to back-end cab	-	210 (60)
	7	Dwell time before departure	45	Included in "Driver's moving time to back-end cab"
Total			420 (270)	750 (300)

Note: (i) number in ( ) means the time in case another driver gets on the back-end cab in advance.

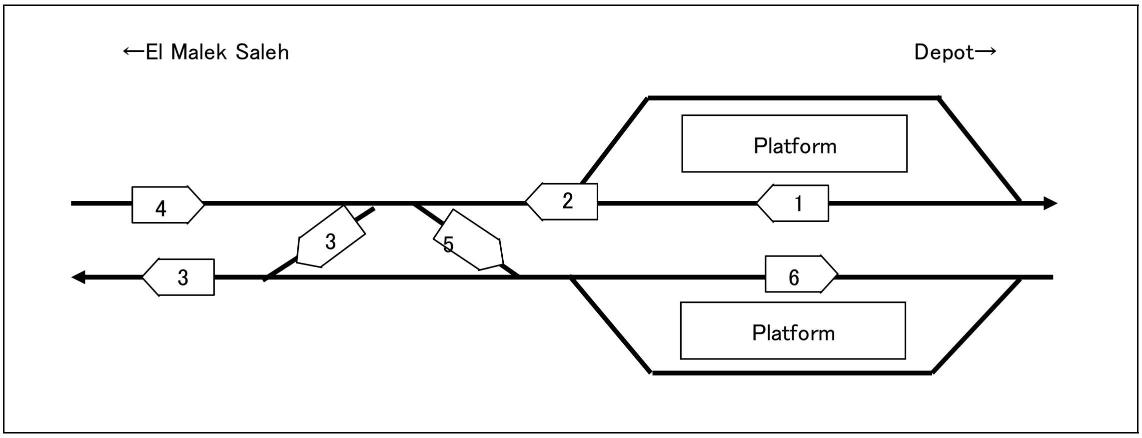
(ii) For details of running time from/to pool track, see Table 4-18.

Source: JICA Study Team

(5) W-Sta. 15 Station

It is planned that the station has a connecting line from/to the depot. For smooth train operation, it is important that trains from/to the depot should be operated without disturbing the operation work in the depot. Therefore, sub-main tracks are provided for each platform, because the station should have enough capacity for temporary stabling to avoid disturbance of the other trains in operation.

With the platform layout of the station, a different departure platform will have to be assigned to each train which may cause some confusion to passengers. As a countermeasure, it is proposed that a passenger information display will be provided on the concourse level to inform the departure platform number for the next train.



Source: JICA Study Team

Figure 4-29 Track Layout of W-Sta. 15 (Scissors are redrawn to Single Crossovers for Clear Explanation)

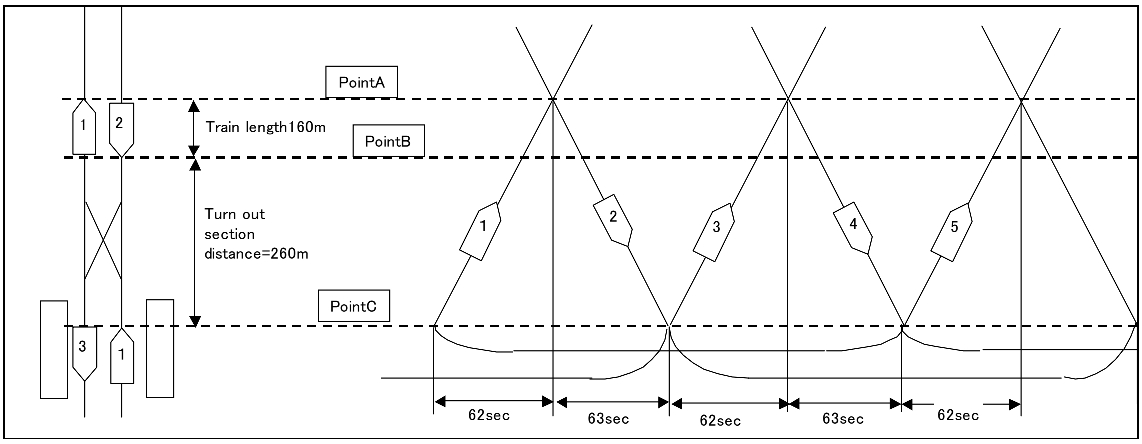
As mentioned in Section 4.2.6, the minimum headway in 2050 is 2 minutes 09 seconds. The track layout of the station should be compatible with a short turn-back operation. According to the calculation with some assumptions, the headway can be minimized to 2 minutes 05 seconds, as shown in Table 4-17. Hence, a 2 minute 09 second operation will make sense.

The turn-back time of the train-set will require twice the minimum headway due to the occupation of the platform. Please refer to Figure 4-30.

Table 4-17 Possible Minimum Headway

Items			Time (sec.)	Remarks
Departure	1	Turnout switching	10	Including the control time from CCP
		Release of brake	7	
	2	Acceleration of the speed to the limited speed	4	Acceleration: assumed as 3.0 km/hr/s. The running distance is 48 m.
	3	Constant speed operation (Time until the rear end of train passes through the turnout section) (Limited speed: 35 km/hr)	41	Speed limitation at turnout is assumed as 35 km/hr. The length of constant speed operation is calculated as 362 m= 250 m + 160 m – 48 m, based on (a) 250 m between the end of platform and the end of turnout section (in consideration of dividing into block section), (b) 160 m of train length, and (c) 48 m for the length to attain constant speed.
		Subtotal	62	
Arrival	4	Turnout switching	10	
	5	Constant speed operation (Time between the turnout section and the point of applying brakes)	40	The length of constant speed operation is assumed as 352 m = 250 m + 160 m – 58 m, based on 58 m for the length from constant speed to stop.
	6	From limited speed to stop	13	Deceleration: 2.5 km/hr/s. The running distance is 58 m.
		Subtotal	63	
Total			125	

Source: JICA Study Team



Source: JICA Study Team

Figure 4-30 Turn-back Time of Train-set at W-Sta. 15 Station

4.2.6 Train Operation Headway

The main purpose of setting the train operation headway is (i) to estimate the required capacity for the signalling facility design, and (ii) to calculate the required number of train-sets. The daily train-kilometres is also calculated based on this data.

(1) Calculation of the Minimum Headway

Hourly number of trains operated during peak hour and the required minimum headway are calculated based on the capacity of rolling stock and the maximum passengers per peak hour per direction (PPHPD).

In order to be on the safe side, the maximum number of PPHPD in both Phase 1 and Phase 2 was assumed to provide the basis for calculating the minimum headway. According to Table 4-12, the section between N-Sta. 7 and N-Sta. 8 has the maximum PPHPD after the completion of Phase 2. However, between 2020 and 2022 (before the completion of Phase 2), the section W-Sta. 5 to W-Sta. 6 in Phase 1 has the maximum PPHPD. The combination of these two numbers provides the basis for calculation of the minimum headway as shown in Table 4-18. It is estimated that by 2050, the required minimum headway will be 2 minutes 09 seconds.

Table 4-18 Calculation of Minimum Headway

Year		2020	2023	2027	2050
PPHPD at peak time	A	29,940	50,760	53,470	55,750
Capacity of a train-set	B	2,000	2,000	2,000	2,000
Number of trains per hour	C=A/B	15	26	27	28
Minimum headway	60/C	4 min. 0 sec.	2 min. 18 sec.	2 min. 13 sec.	2 min. 9 sec.

Source: JICA Study Team

4.2.7 Calculation of Travel Time for Section

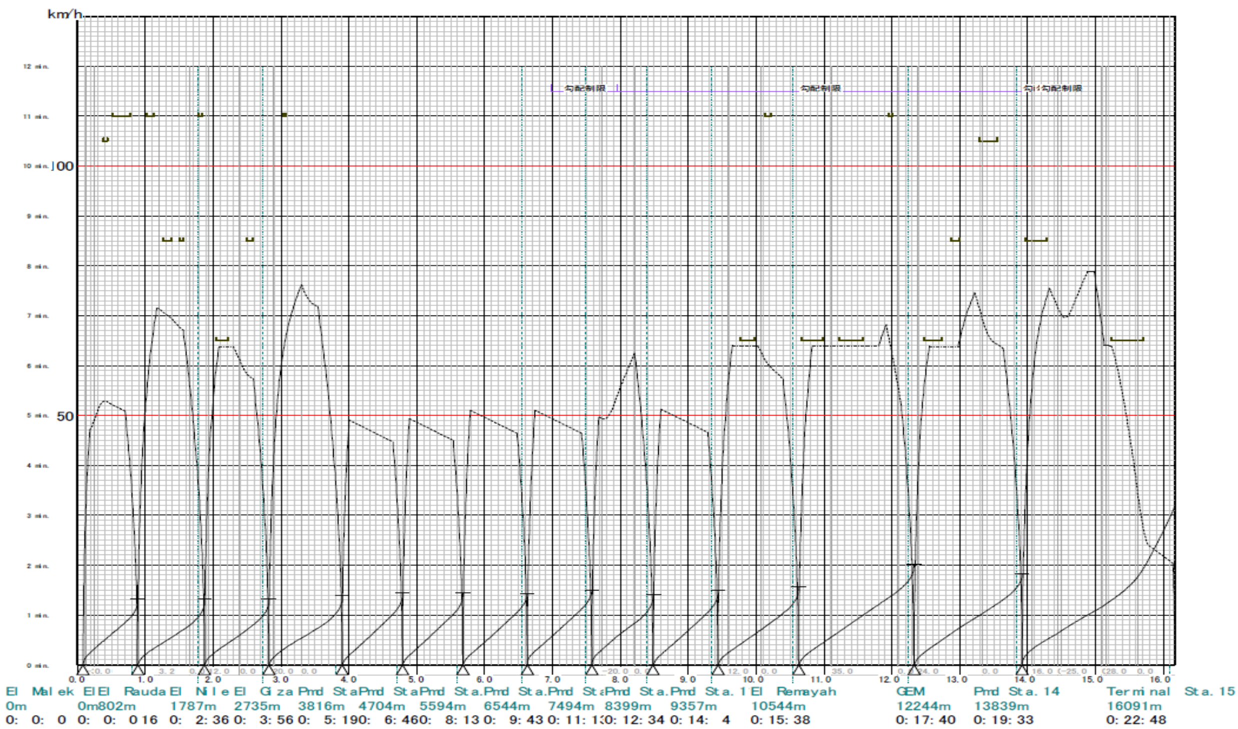
Travel time for section is estimated based on the rolling stock performance, gradient, curve radius and speed limitation at turnout. Dwell time at intermediate stations is assumed at 30 seconds.

The calculation result of travel time for the Phase 1 section (from Station WN-Sta. 1 to W-Sta. 15) is shown in Table 4-19. The train running curve is shown in Figure 4-31. As a result, the travel time for the Phase 1 section is calculated at 28 minutes 45 seconds. It is rounded up to 30 minutes 00 seconds.

Table 4-19　Travel Time from WN-Sta. 1 Station

Station	Distance from the previous station (km)	Travel time from the previous station	Dwell time at previous station	Arrival time
No. 1	0.0	0 min. 00 sec.	—	—
No. 2	0.8	1 min. 15 sec.	—	1 min. 15 sec.
No. 3	1.8	1 min. 30 sec.	0 min. 30 sec.	3 min. 15 sec.
No. 4	2.7	1 min. 30 sec.	0 min. 30 sec.	5 min. 15 sec.
No. 5	3.8	1 min. 30 sec.	0 min. 30 sec.	7 min. 15 sec.
No. 6	4.7	1 min. 30 sec.	0 min. 30 sec.	9 min. 15 sec.
No. 7	5.6	1 min. 30 sec.	0 min. 30 sec.	11 min. 15 sec.
No. 8	6.5	1 min. 30 sec.	0 min. 30 sec.	13 min. 15 sec.
No. 9	7.5	1 min. 30 sec.	0 min. 30 sec.	15 min. 15 sec.
No. 10	8.4	1 min. 30 sec.	0 min. 30 sec.	17 min. 15 sec.
No. 11	9.4	1 min. 30 sec.	0 min. 30 sec.	19 min. 15 sec.
No. 12	10.5	1 min. 45 sec.	0 min. 30 sec.	21 min. 30 sec.
No. 13	12.2	2 min. 15 sec.	0 min. 30 sec.	23 min. 45 sec.
No. 14	13.8	2 min. 00 sec.	0 min. 30 sec.	26 min. 15 sec.
No. 15	16.1	3 min. 15 sec.	-	30 min. 00 sec.
Total	16.1	24 min. 00 sec.	6 min. 00 sec.	30 min. 00 sec.
Average	1.15	1 min. 43 sec.	0 min. 30 sec.	

Source: JICA Study Team



Source: JICA Study Team

Figure 4-31　Train Operation Curve (From WN-Sta. 1 to W-Sta. 15)

4.2.8 Estimation of Rolling Stock Number

The required number of train-sets is estimated based on the concept shown in Figure 4-24.

Regarding turn back time at W-Sta. 15 in Phase 1, the result in Figure 4-30 is applied. In order to minimize the time for changing the driving cab, after arrival, the other standby driver will get on the next front cab. With this operation, the turn back time becomes 3 minutes 05 seconds.

The average speed in 2020 is calculated at 32.2 km/hr (=16.1 km/30 min.). The average speed in Phase 2 is assumed to be the same.

Regarding the turn back time at WN-Sta. 1 in Phase 1, the other standby driver gets on the next front cab after arrival in order to minimize the time for changing the driving cab. With this operation, the turn back time becomes 4 minutes 30 seconds (see Table 4-13).

After the commencement of Phase 2 operation in 2023, the turn-back operation at the northern end is conducted in N-Sta. 17. The layout plan of N-Sta. 17 in Phase 2 should be required to accomplish a 2 minutes 09 seconds headway according to the demand forecast in 2050, although the track layout cannot be fixed yet. To realize the minimum headway, the same type of layout for Station W-Sta. 15 in Phase 1 is considered. In this case, the turn-back time can be twice the minimum headway in consideration of two departure and two arrival tracks and the blocking of other trains due to the crossover (see Figure 4-30).

According to the calculation result shown in Table 4-20, the required number of train-sets is 20 in 2020, 66 in 2023 (starting year of Phase 2 operation), 68 sets in 2027, and 70 sets in 2050.

Table 4-20 Estimation of Required Number of Train-sets

Year	Headway	Distance (km)	Travel time	Spare time	Turn-back time
					At N-Sta. 15
	A	B	C	D	E = A or A x 2
2020	4 min. 00 sec.	16.1	30 min. 00 sec.	1 min. 00 sec.	4 min. 00 sec.
2023	2 min. 18 sec.	33.7	63 min. 00 sec.	1 min. 00 sec.	4 min. 36 sec.
2027	2 min. 13 sec.	33.7	63 min. 00 sec.	1 min. 00 sec.	4 min. 26 sec.
2050	2 min. 09 sec.	33.7	63 min. 00 sec.	1 min. 00 sec.	4 min. 18 sec.
Remarks	From Table 4-18		Average speed : 32.1/hr obtained by C/B		Selected the multiple figures for A equal to or larger than the minimum headway from Table 4-18.

Year	Turn-back time At WN-Sta. 1 of Phase 1 or N-Sta. 17 of Phase 2	Round trip time	Number of train-sets required	Number of spare train-sets	Total number of train-sets
	F = A or F = A x 2	G = (C＋D) x 2 + E + F	H = G / A	I	J = H + I
2020	4 min.00 sec.	70 min.00 sec.	18	2	20
2023	4 min.36 sec.	137 min.42 sec.	60	6	66
2027	4 min.26 sec.	137 min.22 sec.	62	6	68
2050	4 min.18 sec.	137 min.06 sec.	64	6	70
Remarks	Selected the multiple figures for A equal to or larger than that of Table 4-18		The number is rounded up to the nearest integer	10% of H Minimum: 2	

Source: JICA Study Team

The process and method of calculating the rolling stock fleet requirement and purchase schedule over the entire forecast period is illustrated in Table 4-21.

Table 4-21 Calculation of Rolling Stock Requirement and Purchase Schedule - Phases 1 and 2 Combined (Currency Unit: LE million)

Construction of Entire Route (Phases 1 and 2)

Year	PPHPD Phase 1	PPHPD Phase 1+2	Trainset Capacity (persons)	No.trains per hour	Minimum Headway	Distance (Km)	Average Speed (Km/Hr)	Travel Time (Mins)	Spare Time (Mins)	Turn-back Time (Mins)	Round Trip Time (Mins)	Number of trainsets required	Number of spare trainsets 10%	Req.total number of trainsets in fleet	Req. no.of cars cars/train = 8	Purchase schedule	Disbursement -init.purchase unit price (LE mill): 14.07 L.E. mill.
2019																160	2,250.69
2020	29,940		2,000	15	4.000	16.1	32.20	30.00	1.00	8.00	70.00	18	2	20	160	8	112.53
2021	30,410		2,000	16	3.750	16.1	32.20	30.00	1.00	7.50	69.50	19	2	21	168	0	0.00
2022	30,880		2,000	16	3.750	16.1	32.20	30.00	1.00	7.50	69.50	19	2	21	168	360	5,064.05
2023	31,350	50,760	2,000	26	2.308	33.7	32.20	62.80	1.00	9.23	136.82	60	6	66	528	0	0.00
2024		51,438	2,000	26	2.308	33.7	32.20	62.80	1.00	9.23	136.82	60	6	66	528	16	225.07
2025		52,115	2,000	27	2.222	33.7	32.20	62.80	1.00	8.89	136.48	62	6	68	544	0	0.00
2026		52,793	2,000	27	2.222	33.7	32.20	62.80	1.00	8.89	136.48	62	6	68	544	0	0.00
2027		53,470	2,000	27	2.222	33.7	32.20	62.80	1.00	8.89	136.48	62	6	68	544	0	0.00
2028		53,569	2,000	27	2.222	33.7	32.20	62.80	1.00	8.89	136.48	62	6	68	544	0	0.00
2029		53,668	2,000	27	2.222	33.7	32.20	62.80	1.00	8.89	136.48	62	6	68	544	0	0.00
2030		53,767	2,000	27	2.222	33.7	32.20	62.80	1.00	8.89	136.48	62	6	68	544	0	0.00
2031		53,867	2,000	27	2.222	33.7	32.20	62.80	1.00	8.89	136.48	62	6	68	544	0	0.00
2032		53,966	2,000	27	2.222	33.7	32.20	62.80	1.00	8.89	136.48	62	6	68	544	16	225.07
2033		54,065	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2034		54,164	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2035		54,263	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2036		54,362	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2037		54,461	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2038		54,560	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2039		54,660	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2040		54,759	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2041		54,858	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2042		54,957	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2043		55,056	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2044		55,155	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2045		55,254	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2046		55,353	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2047		55,453	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2048		55,552	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2049		55,651	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
2050		55,750	2,000	28	2.143	33.7	32.20	62.80	1.00	8.57	136.16	64	6	70	560	0	0.00
																Total	***7,877.40***

Phase 1 in operation

Phase 2 in operation

Source: Table constructed by JST Financial Specialist, with assistance from JST O&M Specialist.

4.2.9 Estimation of Daily Train Number

The estimated demand in Table 4-12 shows only the "demand for peak hour", not the demand for a day. This can be calculated using the peak ratio estimated from the statistical data of the existing Cairo Metro. Therefore, the train number per each hour of Metro Line 4 can be calculated based on the ratio of the average number of trains per hour to the peak hour train number of the existing metro. The daily number of trains operated can be calculated by adding up these hourly numbers of trains.

(1) Hourly Number of Trains of Existing Line

Table 4-22 shows the hourly number of trains operating on Metro Line 2 (in both the up and down directions). The number of trains on holidays like Friday is approximately 65% of that on normal working day. The peak hour is between eight and nine in the morning.

Table 4-22 Hourly Number of Trains Operating on Metro Line 2

Time zone	Working day	Holidays	Remarks
4-	4	4	
5-	8	6	
6-	34	12	
7-	41	16	
8-	44	24	Peak Hour
9-	38	24	
10-	30	24	
11-	30	24	
12-	33	24	
13-	40	24	
14-	40	24	
15-	40	24	
16-	40	24	
17-	38	20	
18-	30	20	
19-	24	20	
20-	20	20	
21-	20	20	
22-	12	13	
23-00	12	11	
Total number	578	378	

Source: ECMOU

(2) Estimated Hourly Number of Trains on Metro Line 4

The required hourly number of trains is calculated for both weekdays and holidays, based on the following formula:

"Required hourly number of trains on Metro Line 4" = "Hourly number of trains on Metro Line 2 (Table 4-22)" x "The train number in the peak hour of Metro Line 4 (Table 4-18)" / "The train number in the peak hour of Metro Line 2 (Table 4-22)"

Table 4-23 Hourly Number of Trains on Metro Line 4 (Working Day, One-way)

Time zone	2020	2023	2027	2050
4-	1	2	2	3
5-	3	5	5	5
6-	12	20	21	22
7-	14	24	25	26
8-	15	26	27	28
9-	13	22	23	24
10-	10	18	18	19
11-	10	18	18	19
12-	11	20	20	21
13-	14	24	25	25
14-	14	24	25	25
15-	14	24	25	25
16-	14	24	25	25
17-	13	22	23	24
18-	10	18	18	19
19-	8	14	15	15
20-	7	12	12	13
21-	7	12	12	13
22-	4	7	7	8
23-00	4	7	7	8
Total number	198	343	353	367

Source: JICA Study Team

Table 4-24 Hourly Number of Trains on Metro Line 4 (Holiday, One-way)

Time zone	2020	2023	2027	2050
4-	1	2	2	3
5-	2	4	4	4
6-	4	7	7	8
7-	5	9	10	10
8-	8	14	15	15
9-	8	14	15	15
10-	8	14	15	15
11-	8	14	15	15
12-	8	14	15	15
13-	8	14	15	15
14-	8	14	15	15
15-	8	14	15	15
16-	8	14	15	15
17-	7	12	12	13
18-	7	12	12	13
19-	7	12	12	13
20-	7	12	12	13
21-	7	12	12	13
22-	4	8	8	8
23-00	4	7	7	7
Total number	127	223	233	240

Source: JICA Study Team

(3) Estimation of Yearly Number of Trains and Train-kilometres

Yearly train-km is used as the basis for the estimation of O&M costs. Daily train-km is calculated by multiplying the result in Table 4-23 and Table 4-24 with the route length in each year. Yearly train-km is then obtained by multiplying working days per week and number of weeks per year by daily train-km, as shown in Table 4-25.

Table 4-25 Estimated Daily Number of Trains (Working day, One-way) and Train-kilometres

Items	Year	2020	2023	2027	2050
Number of trains per hour per direction	A	15	26	27	28
Number of trains per direction per day (Working day)	B (From Table 4-23)	198	343	353	367
Number of trains per day (Holidays)	C (From Table 4-24)	127	223	233	240
Train-km (Working day)	D = 2 x B x Route km	6,376	23,118	23,792	24,736
Train-km (Holidays)	E = 2 x C x Route km	4,089	15,030	15,704	16,176
Train-km per year (000)	F = 52 x (6 x D + E)	2,202	7,994	8,240	8,559

Route km: = 16.1 km (2020), = 16.1 + 17.6 = 33.7 km (2023, 2027, 2050)
Source: JICA Study Team

4.3 Emergency/Disaster Incident Management

In order to operate the metro properly and safely, the management and countermeasure for the emergency/disaster incident are very important issues. Fire, flooding, strong wind (at grade or elevated section), etc. are considered as the emergency/disaster incidents for the metro. Especially, the fire fighting and its management/countermeasure is most crucial matter for the underground section of metro operation. Therefore, the fire management and countermeasure is mainly described in this section.

4.3.1 Characteristics of Fire Accident in Tunnel and Underground Station

In recent years, there have been many fatal fire accidents that occurred in tunnel and underground all over the world. After these fire accidents, there have been hard discussions locally and internationally how to manage fire on tunnels for transportation and underground station. However, it is difficult to come to a final conclusion as international standard because the condition and requirement of each country is different. In some country, the regulation/standard for fire management/countermeasure is becoming very strict while it is not in others. According to the type of tunnels and underground structures (road tunnel, railway tunnel or metro and its underground station), the characteristics of the cause of fire accident, fire load/size and escape method are also different. However, the differences of these characteristics are sometimes not well studied and the management and countermeasures are planned and carried out without their consideration.

In order to explain the differences of the fire accidents, the major fire accident of road tunnel, metro tunnel and stations which have taken place around the world are listed and its characteristics are studied as follows:

(1) Fire Accident of Metro Tunnel and Underground Station

The major fire accidents of metro tunnel and underground station in the world are shown in Table 4-26. Many fire accidents occurred in metros in the past but fatal fire accidents which killed many passengers are limited. In most cases, not so much passengers were killed but just injured by breathing the smoke. Major mortal metro accidents were Moscow Metro, Russia (7 killed, 1991), Baku Metro, Azerbaijan (256 killed, 1995) and Dague Metro, South Korea (197 killed, 2003). These accidents were rare cases that the countermeasures and management for the fire accident were not well considered and executed. The case of the fatal accident in Dague, South Korea is explained in the following section.

The major causes of fire accidents in metro tunnel and underground station are arson, fire from motor of rolling stock, cable fire, etc. The damage of the fire accidents in metro tunnel and underground station is relatively small and its reasons and characteristics are as follows:

- Train is operated and controlled by the Metro Operation Organization. Ratio of fatal accident is quite smaller than that of road tunnel.
- In many countries and cities, station and rolling stocks are basically constructed and composed of noncombustible material or fire-retardant material.
- The metro is used for commuting or other passenger's purpose. The hand baggage brought by the passengers is also limited. The freight train which carries flammable material does not pass in the metro.
- In case of fire in tunnel, the basic principle of the train operation is to run to the next station. The distance between stations is relatively short in metro (approximately 1 km or less) and the travelling time from station to station is at most 2-3 minutes. Hence, the passengers can escape through station.

The management and countermeasure for fire accidents should be prepared and designed, taking into consideration the abovementioned conditions and characteristics.

Table 4-26 Major Fire Accidents with Passenger's Damage of Metro (Tunnel and Underground Station) of the World since 1980

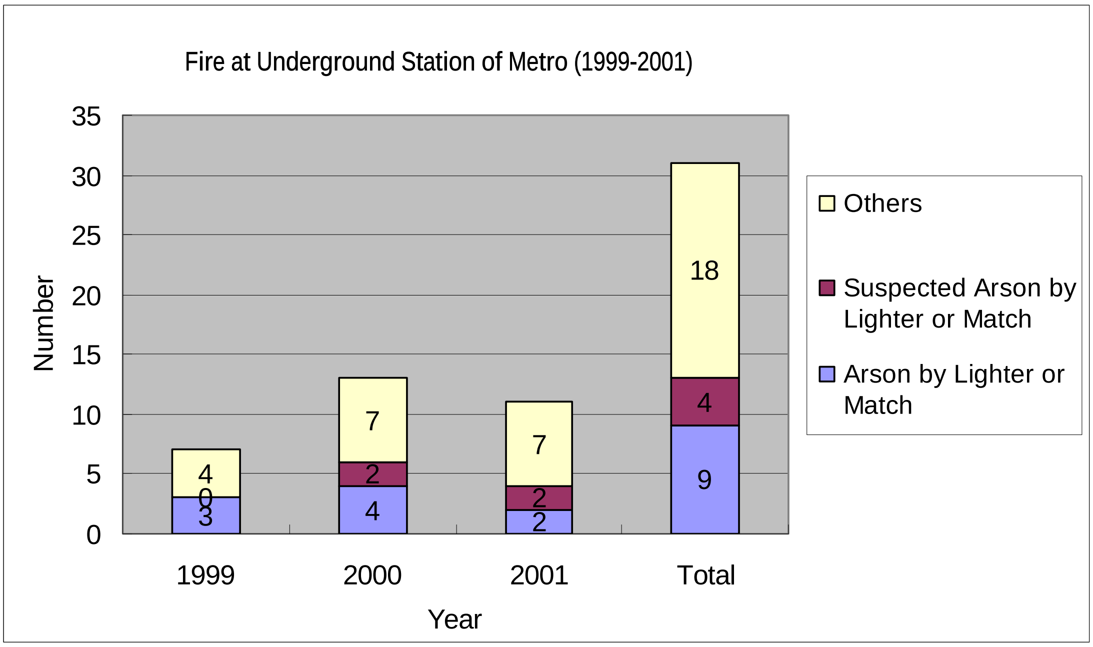
No.	Tunnel	Year of Fire Accident	Country Location	Where Fire Occurred	Origin/Reason of Fire	Damage	
						People	Rolloing Stock
1	Altora Metro	1980	Germany Hamburg		Arson	4 injured	Some
2	New York Metro	1980	USA New York			11 injured	
3	New York Metro	21/Apr./1981	USA New York	600m from station	Fault in the Current Collector of Rolling Stock	24 injured	
4	New York Metro	29/Apr./1981	USA New York	Station	Undercar fire in station	2 injured	
5	New York Metro	May/1981	USA New York	Station	Electrical Fault	16 injured	
6	London Metro	1981	UK London	Between Stations		1 dead, 15 injured	
7	New York Metro	March/1982	USA New York	Station	Motor of Rolling Stock	86 injured	
8	New York Metro	June/1982	USA New York		Rolling Stock	10 injured	4 Rolling Stock
9	New York Metro	April/1984	USA New York		Smoke from Cable	39 injured	4 Rolling Stock
10	New York Metro	June/1984	USA New York	Between Stations	Rolling Stock Motor exploded	23 injured	Some
11	New York Metro	July/1984	USA New York	Station	Underneath of Rolling Stock	24 injured	Some
12	New York Metro	4/Oct./1984	USA New York	Station	Rubbish	54 injured	
13	Landungsbruken Metro	1984	Germany Hamburg		Arson	1 injured	
14	Oxford Circus Metro	1984	UK London	Maintenance Tunnel	Equipment in Tunnel	15 injured	
15	Paris Metro	1985	France Paris	Station	Rubbish	6 injured	
16	Mexico City Metro	1985	Mexico Mexico City		Rolling Stock	1700 injured	
17	New York Metro	1990	USA New York	Near Station	Cable	2 dead, 200 injured	
18	Moscow Metro	1991	Russia Moscow	Station	Electric Failure Under Train	7 dead, 10 injured	Some
19	New York Metro	March/1992	USA New York	Between Station	Undercar fire in Tunnel	86 injured	
20	New York Metro	Oct./1992	USA New York		Electric Failure of Rolling Stock	51 injured	
21	Baku Metro	1995	Azerbaijan Baku	Between Station	Electric Failure of 4th Rolling Stock	260 dead, 256 injured	Some
22	New York Metro	1999	USA New York	Station	Rubbish	more than 51 injured	
23	Amsterdam Metro	1999	Netherlands Amsterdam	Station		2 injured	
24	Berlin Metro	2000	Germany Berlin	Station		28 injured	
25	Tronto Metro	2000	Canada Tronto	Old Mill Station	Fefuse from Old Mill	3 injured	
26	Düsseldorf Metro	2001	Germany Düsseldorf		Roof of Rolling Stock	2 injured	
27	Jungangno Metro	2003	South Korea Daegu	Junganno Station	Arson with Fuel	197 dead and 148 injured	

Source: The Handbook of Tunnel Fire Safety, 2004

(2) Underground Station Fire in Japan

In order to explain the characteristic of the fire in the station, the statistics of cause of station fire in Japan is indicated as example.

Many metros have been constructed in Japan since 1927. There are 41 lines in 11 cities and the number of the underground stations exceeds 560 among 724 stations of metros as of year 2009. Since many metro lines and its stations are operated, about 10 fire accidents in underground stations occur every year in Japan. The main reason of these fire accidents at the underground stations are arson using match or lighter (approximately 40%). Therefore, it is reasonable to consider the arson fire as one of the assumed design fire.



Source: Fire and Disaster Management Agency, Japan

Figure 4-32 Fire at Underground Station of Metro in Japan (1999-2001)

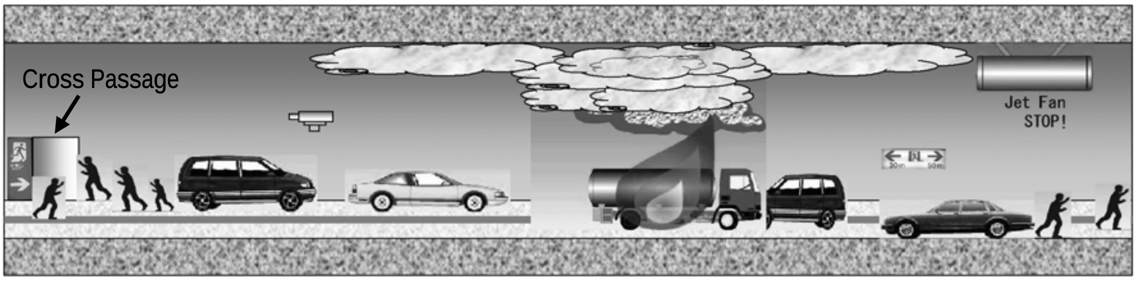
(3) Fire Accident at Road Tunnel

The major fire accidents at road tunnel which happened in the world are tabulated in Table 4-27. The fire accident at road tunnel has a scale far lager than that of the metro tunnel and underground station. Consequently, the fire in road tunnel tends to be large scale accidents with lost of tunnel user's life. The reasons of large fire scale and its characteristics are summarized as follows:

- Each car has own fuel (gasoline or diesel) and it intensifies the flame in case of fire accident. In addition, some trucks bring flammable materials and it is also dangerous.
- The car is driven by each tunnel user and it is difficult for road operator/administrator to control the whole operation in the road tunnel. Therefore, the collision of cars (crush accident) sometimes occurs. In most

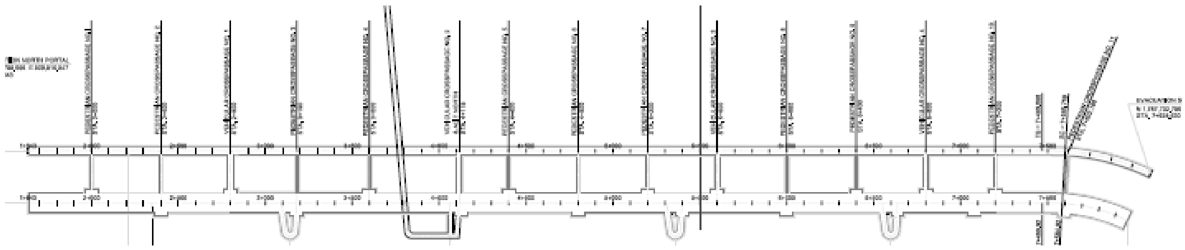
cases, the fire accident is triggered by the collision of cars.

- If the fire accident happens in the road tunnel, cars are stopped around the fire point. Thus, in a long tunnel or congested city tunnel, it is difficult for a car to escape outside of the tunnel and the tunnel users have to evacuate from their car to the evacuation or another parallel tunnel through cross passages (see Figure 4-33 and Figure 4-34).
- Many monitoring systems for fire detection and fire fighting facilities are installed in the road tunnel, especially for long and congested tunnel, due to the above mentioned reasons.



Source: JICA Study Team

Figure 4-33 Fire Accident in Road Tunnel (Long Tunnel or Congested City Tunnel)



Source: JICA Study Team

Figure 4-34 Example of Cross Passages between Main Road Tunnel and Evacuation Tunnel (L = 6.3 km)

Table 4-27 Major Fire Accidents at Road Tunnel of the World

Tunnel	Year of Construction	Year of Fire Accident	Country Location	Length (m)	Vehicle where Fire Occurred	Load	Origin of Fire	Damage	
								People	Vehicles
Holland	1927		USA New York	2,550	1 lorry	11t carbon visulphide	Fall of load	66 injured	10 lorries destroyed 13 cars badly dameged
Billweder-Meorfleet	1963		Germany Hamburg	243	1 lorry trailer	14t plastic aggregate in sacks	Blockage of brakes		1 trailed destroyed
Velsen	1957	1978	Holland Velsen	770	2 lorries and 4 cars		Front-rear collision	5 dead and 5 injured	2 lorries and 4 cars destroyed
Nihonzaka	1969	1979	Japan Shizuoka	2,045	4 lorries and 2 cars		Front-rear collision	7 dead and 2 injured	179 vehicles destroyed
Kajiwara		1980	Japan	740				1 dead	
Caldecott	1964	1982	USA Oakland	1,028	1 lorry, 1 coach and 1 car	33,000 litres of petrol	Front-rear collision	7 dead and 2 injured	3lorries, 1coach and 4cars
Pecorile		1983	Italy	600				8 dead	
St. Gotthard	1980		Switzerland Goschenen - Airolo	16,321	1 lorry	Rolls of plastic sheet	Lorry engine fire		1 lorry destroyed
Frejus	1980		France-Italy	12,868	1 lorry	Plastic Material	Gear box failure		1 lorry destroyed
Guadarrama	1972		Spain Guadarrama	3,330	1 lorry	Drums of pine resin			1 lorry destroyed
L'Ame		1986	France	1,105				3 dead	
Gumefens		1987	Switzerland	340				2 dead	
Serra a Ripoli		1993	Italy	442				4 dead	
Huguenot	1988	1994	South Africa	3,755				1 dead	
Pfander	1980	1995	Austria	6,719				3 dead	
Isola delle Femmine		1996	Italy Palermo	148	1 tanker with liquid gas and 1 little bus		Front-rear collision	5 dead and 20 injured	1 tanker, 1bus and 18 cars
Mont Blanc	1965	1999	France-Italy	11,600	Lorry with flour and magarine		Oil leakage Motor	41 dead	23 lorries, 10 cars, 1morot cycle and 2 fire engine
Tauern	1975	1999	Austria Salzburg-Spittal	6,401	Lorry with Paint		Front-rear collision	12 dead and 49 injured	14 lorries and 26 cars
Seijestad		2000	Norway Drammen-Haugesund	1,272	Fire started in one of the cars and spread to others		Front-rear collision	6 injured	1 lorry, 4 cars and 1MC
Prapontin		2001	Italy A32-Torino-Bardonecchia	4,409				19 injured	
Gleinalm	1978	2001	Austlia A9 near Graz	8,320	Car		Front-rear collision	5 dead and 4 injured	
St Gotthard	1980	2001	Switzerland Goschenen - Airolo	16,321	2 Trucks		Front-front collision	11 dead	40 vehicles
Viamala		2006	Switzerland (border with Italy and Austria)	750	Bus and Car		Front-front collision	9 dead	

Source: JICA Study Team

(4) Fatal Fire Accident in Dague, South Korea, 2003

The fatal fire accident which killed 197 persons and injured 148 persons occurred in Dague Metro in South Korea in February 2003. This accident provided heavy impact on the metro operators all over the world. It is important and valuable to know the lessons from the worst fire accident of the metro.

This accident was caused by an arson attack on the train which stopped at Jungganno Station in Dague City. The lunatic man brought 2-4 litters gasoline in two pet bottles and set fire using a lighter. The seat and floor started to flame and fire spread rapidly in the car. The rolling stock was made of combustible materials with toxic gas such as polyester, urethane foam, FRP, etc. The regulation was established in 1998 that the material for the rolling stock of metro had to be non-combustible material. However, the rolling stocks of the fire accident were made in 1997 and the regulation for use of the non-combustible material for the rolling stock was not yet obeyed and enforced appropriately as of the year 2003.

Source: Fire and Disaster Management Agency, Japan

Figure 4-35 Fatal Fire Accident at the Dague Metropolitan Subway, 2003

The Central Control Point (CCP) did not comprehend the actual situation of the fire accident and did not instruct the train running on the opposite track not to approach or pass through the station on fire. In most metros of the other countries, it is regulated to instruct other trains not to approach and to pass through a station if it is on fire. However, the principle of the train operation in case of fire accident was not respected in the Dague Metro.

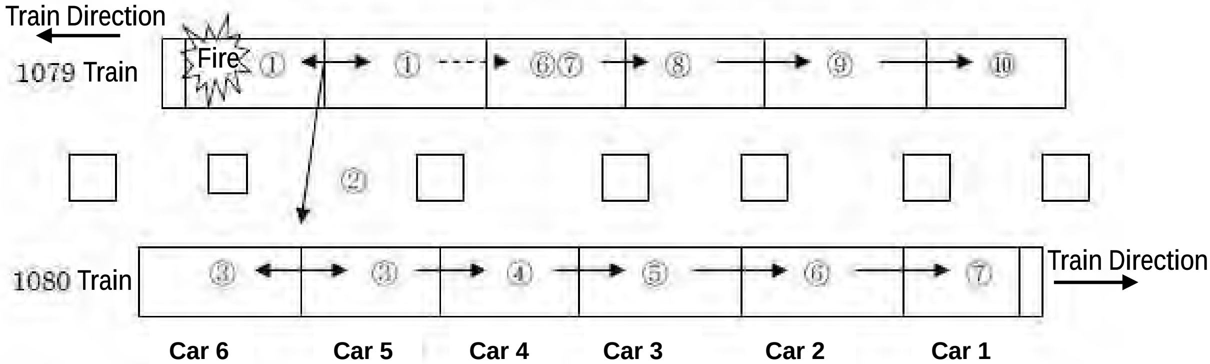
The CCP tried to evacuate the passengers in the train on the other track through the station. The train which arrived on the opposite platform caught fire soon (the sequence of the fire spread is illustrated in Figure 4-37). After that, the power supply to the train and station failed and the driver who was upset ran away with the master key of the car. The door of the train was closed and the passengers were locked in the train on fire. As a result, more than 90% of the victims were passengers of the train on the opposite track and the body of 142 passengers (79% of the dead persons) were found in the burnt train on the opposite track. Meanwhile, no dead persons were found in the car burnt by the arsonist.

The lessons were obtained from this accident and the most important issue on fire accident management for metro and underground station was reconfirmed and highlighted as follows:

- Use of noncombustible materials for the rolling stock and station is very important. The combustible material of the rolling stock and station aggravated the fire.
- Suitable management for train operation and evacuation is also very important. In the case of the Dague Metro fire accident, most of the victims were killed by the secondary accident caused by inappropriate instruction and action of the dispatcher, driver and station staff.

Source: Japan Society of Civil Engineer

Figure 4-36 Combustible Material in the Rolling Stock of Dague Metro (Polyester, Urethane Foam, FRP, etc.)



Source: Fire and Disaster Management Agency, Japan

Figure 4-37 Sequence of the Fire that Spread at Dague Metro

Based on the characteristics and examples of the fire accident in tunnel and underground station described in this section, the standards for fire accident management are studied in the following section.